

CBSE Class 12 Physics Question Paper 2023 with Solution PDF-Set 55/5/3

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) This question paper contains **35** questions. **All** questions are compulsory.
- (ii) Question paper is divided into **FIVE** sections – Section **A, B, C, D** and **E**.
- (iii) **In section – A** : question number **1 to 18** are Multiple Choice (MCQ) type questions carrying **1** mark each.
- (iv) **In section – B** : question number **19 to 25** are Short Answer-1 (SA-1) type questions carrying **2** marks each.
- (v) **In section – C** : question number **26 to 30** are Short Answer-2 (SA-2) type questions carrying **3** marks each.
- (vi) **In section – D** : question number **31 to 33** are Long Answer (LA) type questions carrying **5** marks each.
- (vii) **In section – E** : question number **34 and 35** are case-based questions carrying **4** marks each.
- (viii) There is no overall choice. However, an internal choice has been provided in **2** questions in Section – **B**, **2** questions in Section – **C**, **3** questions in Section – **D** and **2** questions in Section – **E**.
- (ix) Use of calculators is NOT allowed.

$$c = 3 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\text{Mass of electron } (m_e) = 9.1 \times 10^{-31} \text{ kg}$$

$$\text{Mass of neutron} = 1.675 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton} = 1.673 \times 10^{-27} \text{ kg}$$

$$\text{Avogadro's number} = 6.023 \times 10^{23} \text{ per gram mole}$$

$$\text{Boltzmann constant} = 1.38 \times 10^{-23} \text{ JK}^{-1}$$

Section A (18 marks)

1. An electric dipole of length 2 cm is placed at an angle of 30° with an electric field 2×10^5 N/C. If the dipole experiences a torque of 8×10^{-3} Nm, the magnitude of either charge of the dipole, is [1 mark]

- (A) $4 \mu\text{C}$
- (B) $7 \mu\text{C}$
- (C) 8 mC
- (D) 2 mC

Correct Answer: (A) $4 \mu\text{C}$

Solution:

Concept:

- The dipole moment has magnitude $p = q\ell$, where q is either charge and ℓ is the full separation between the charges.
- The torque in a uniform field is $\tau = pE \sin \theta$, where θ is the angle between the dipole moment and the field.

Step 1: Convert the dipole length The stated length is the full separation, so $\ell = 2 \text{ cm} = 2 \times 10^{-2} \text{ m}$. Also, $\sin 30^\circ = 1/2$. There is no additional factor of two in $p = q\ell$.

Step 2: Calculate the charge and compare the options Using $\tau = q\ell E \sin \theta$,

$$q = \frac{8 \times 10^{-3}}{(2 \times 10^{-2})(2 \times 10^5)(1/2)} = 4 \times 10^{-6} \text{ C}.$$

The result is in microcoulombs. The value $7 \mu\text{C}$ does not give the stated torque, and the two millicoulomb values are much too large.

Step 3: Conclusion The magnitude of either charge is $4 \mu\text{C}$. Hence, the correct option is (A).

Quick Tip to Solve: Use the full stated dipole length in $p = q\ell$; convert centimetres to metres before substituting.

2. Two horizontal thin long parallel wires, separated by a distance r carry current I each in the opposite directions. The net magnetic field at a point midway between them, will be [1 mark]

- (A) zero
- (B) $\frac{\mu_0 I}{2\pi r}$, vertically downward
- (C) $\frac{2\mu_0 I}{r}$, vertically upward
- (D) $\frac{\mu_0 I}{\pi r}$, vertically downward

Correct Answer: No printed option matches $2\mu_0 I/(\pi r)$; the absolute vertical direction is also unspecified.

Solution:

Concept:

- For a long straight wire, $B = \mu_0 I/(2\pi d)$, where d is the perpendicular distance from that wire.
- For opposite currents, the right-hand thumb rule shows that the two fields between the wires point in the same direction, so their magnitudes add.

Step 1: Find the field of each wire The midpoint is at distance $d = r/2$ from each wire. Hence each wire contributes

$$B_1 = B_2 = \frac{\mu_0 I}{2\pi(r/2)} = \frac{\mu_0 I}{\pi r}.$$

The fields cannot cancel because the currents run in opposite directions.

Step 2: Add the fields and inspect the printed choices The net magnitude is

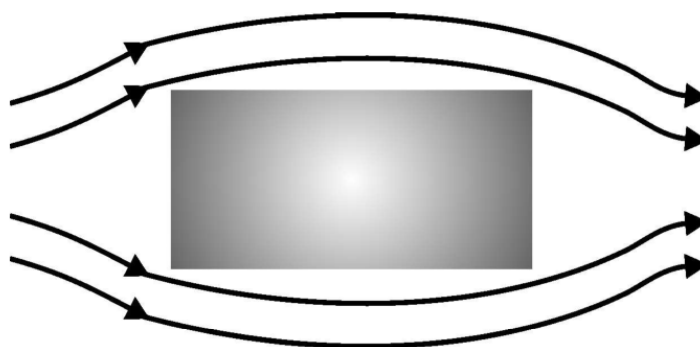
$$B_{\text{net}} = B_1 + B_2 = \frac{2\mu_0 I}{\pi r}.$$

Option (A) wrongly assumes cancellation. Options (B) and (D) have respectively one quarter and one half of this magnitude. Printed option (C) is $2\mu_0 I/r$, with no π in its denominator, and is therefore also incorrect. Furthermore, the statement does not specify which wire carries current in which direction, so it does not uniquely determine upward versus downward.

Step 3: Conclusion The net field has magnitude $2\mu_0 I/(\pi r)$. None of the printed options gives this magnitude; no unique correct option can be selected.

Quick Tip to Solve: At the midpoint use $r/2$ for each wire, then add both fields for opposite currents. Check every factor in the printed options.

3. Which of the following cannot modify an external magnetic field as shown in the figure? [1 mark]



- (A) Nickel
- (B) Silicon
- (C) Sodium Chloride
- (D) Copper

Correct Answer: (A) Nickel

Solution:

Concept:

- A diamagnetic material acquires magnetisation opposite to an applied magnetic field; its relative permeability is slightly less than one.
- A ferromagnetic material such as nickel strongly reinforces the field within it and tends to concentrate magnetic field lines.

Step 1: Identify the behaviour in the figure The field lines bend away from the specimen instead of crowding into it. The sketch therefore represents exclusion of some magnetic flux, the characteristic response of a diamagnetic substance. The question asks which material cannot show this response.

Step 2: Compare all four materials Silicon, sodium chloride and copper are diamagnetic, so each can produce the type of field distortion shown. Nickel is ferromagnetic: it attracts and concentrates field lines rather than expelling them in this way. Thus the word “cannot” selects the material with the opposite magnetic behaviour.

Step 3: Conclusion Nickel cannot modify the external field in the illustrated manner. Hence, the correct option is (A).

Quick Tip to Solve: Lines bending away indicate diamagnetism; lines crowding inside indicate a material that reinforces the applied field.

4. A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is [1 mark]

- (A) 0.1 V
- (B) 0.5 V
- (C) 0.75 V
- (D) 1.0 V

Correct Answer: (D) 1.0 V

Solution:

Concept:

- Faraday's law gives the induced emf magnitude as $|\mathcal{E}| = N|d\Phi/dt|$, where N is the number of turns.
- For a fixed coil, flux per turn is $\Phi = BA \cos \theta$, where θ is measured between the field and the normal to the coil.

Step 1: Find the area and orientation factor The plane of the coil is perpendicular to the field, so its normal is parallel to the field and $\cos \theta = 1$. The area of one square turn is

$$A = (10 \times 10^{-2})^2 = 10^{-2} \text{ m}^2.$$

The centimetre conversion must be squared along with the side.

Step 2: Use the rate of change of magnetic flux With $N = 100$ and $dB/dt = 1 \text{ T s}^{-1}$,

$$|\mathcal{E}| = NA \frac{dB}{dt} = 100 \times 10^{-2} \times 1 = 1.0 \text{ V}.$$

The other three choices are smaller than the flux-linkage rate. Lenz's law determines the polarity, while the question asks only for the emf magnitude.

Step 3: Conclusion The induced emf is 1.0 V. Hence, the correct option is (D).

Quick Tip to Solve: Convert the side to metres and square it before multiplying by the turns and dB/dt .

5. Which one of the following electromagnetic radiation has the least wavelength?

[1 mark]

- (A) Gamma rays
- (B) Microwaves
- (C) Visible light
- (D) X-rays

Correct Answer: (A) Gamma rays

Solution:

Concept:

- All electromagnetic waves travel at speed c in vacuum, with $c = \nu\lambda$, where ν is frequency and λ is wavelength.
- In the standard electromagnetic spectrum, gamma rays occupy the highest-frequency, shortest-wavelength region.

Step 1: Order the listed spectrum regions The conventional order of decreasing wavelength among the four choices is microwaves, visible light, X-rays, then gamma rays. Moving in this direction corresponds to increasing frequency and photon energy.

Step 2: Select the shortest-wavelength region Microwaves have much longer wavelengths than visible radiation. X-rays have shorter wavelengths than visible light, but gamma rays lie beyond X-rays at the high-frequency end of the standard spectrum. Since $\lambda = c/\nu$, selecting the greatest frequency gives the least wavelength; this rules out the other three listed regions.

Step 3: Conclusion Gamma rays have the least wavelength among the listed radiation types. Hence, the correct option is (A).

Quick Tip to Solve: Remember the high-frequency end in order: ultraviolet, X-rays, gamma rays; wavelength decreases along this sequence.

6. In a Young's double-slit experiment, the screen is moved away from the plane of the slits. What will be its effect on the following?

- (i) Angular separation of the fringes.
- (ii) Fringe-width.

[1 mark]

- (A) Both (i) and (ii) remain constant.
- (B) (i) remains constant, but (ii) decreases.
- (C) (i) remains constant, but (ii) increases.
- (D) Both (i) and (ii) increase.

Correct Answer: (C) (i) remains constant, but (ii) increases.

Solution:

Concept:

- The linear fringe width is $\beta = \lambda D/d$, with wavelength λ , slit separation d , and slit-to-screen distance D .
- For small angles, the angular separation of adjacent fringes is $\Delta\theta = \beta/D = \lambda/d$.

Step 1: Examine angular separation Moving the screen changes D but does not change λ or d . Since $\Delta\theta = \lambda/d$ contains no D , the angular separation stays constant. The directions of the bright fringes

are fixed by the path-difference condition at the slits.

Step 2: Examine the fringe width on the screen The screen is moved away, so D increases. From $\beta = \lambda D/d$, the linear fringe width increases in direct proportion to D . Thus (A) incorrectly keeps the width fixed, (B) incorrectly decreases it, and (D) incorrectly increases the angular separation.

Step 3: Conclusion Angular separation remains constant while fringe width increases. Hence, the correct option is (C).

Quick Tip to Solve: Distinguish angle from distance: a fixed angle spans a larger linear separation on a more distant screen.

7. E , c and ν represent the energy, velocity and frequency of a photon. Which of the following represents its wavelength? [1 mark]

- (A) $\frac{h\nu}{c^2}$
- (B) $h\nu$
- (C) $\frac{hc}{E}$
- (D) $\frac{h\nu}{c}$

Correct Answer: (C) $\frac{hc}{E}$

Solution:

Concept:

- Planck's relation for a photon is $E = h\nu$, where h is Planck's constant and ν denotes the printed frequency symbol.
- The wave relation is $c = \nu\lambda$, so a photon's wavelength is speed divided by frequency.

Step 1: Eliminate the frequency From the energy relation, $\nu = E/h$. Substitute this into the wave relation:

$$\lambda = \frac{c}{\nu} = \frac{c}{E/h} = \frac{hc}{E}.$$

Thus increasing photon energy decreases its wavelength.

Step 2: Check the other expressions by their dimensions The expression $h\nu$ in (B) is energy. Dividing it by c^2 , as in (A), gives dimensions of mass, whereas dividing by c , as in (D), gives momentum. None has dimensions of length. In contrast, hc/E has units $(\text{J s})(\text{m s}^{-1})/\text{J} = \text{m}$.

Step 3: Conclusion The wavelength is $\lambda = hc/E$. Hence, the correct option is (C).

Quick Tip to Solve: Combine $E = h\nu$ and $c = \nu\lambda$; dimensional analysis then rejects energy, mass and momentum expressions.

8. The ratio of the nuclear densities of two nuclei having mass numbers 64 and 125 is

[1 mark]

- (A) $\frac{64}{125}$
(B) $\frac{4}{5}$
(C) $\frac{5}{4}$
(D) 1

Correct Answer: (D) 1

Solution:

Concept:

- The nuclear radius is approximately $R = R_0 A^{1/3}$, where A is mass number and R_0 is a constant.
- Nuclear mass is approximately Am_N , where m_N is the mean nucleon mass; density is mass divided by volume.

Step 1: Express density in terms of mass number For an approximately spherical nucleus,

$$\rho = \frac{Am_N}{(4/3)\pi R^3} = \frac{Am_N}{(4/3)\pi R_0^3 A} = \frac{3m_N}{4\pi R_0^3}.$$

The factor A cancels because both nuclear mass and nuclear volume increase in proportion to the number of nucleons.

Step 2: Compare the two given nuclei The nuclei with mass numbers 64 and 125 therefore have approximately equal densities. The choice $64/125$ compares masses without accounting for volume. The ratio $4/5$ is their radius ratio, since $64^{1/3}/125^{1/3} = 4/5$, and $5/4$ is its inverse; neither is the density ratio.

Step 3: Conclusion The ratio of nuclear densities is 1 : 1, or 1. Hence, the correct option is (D).

Quick Tip to Solve: In nuclear-density questions, cube $R \propto A^{1/3}$: volume and mass both scale as A , so their ratio is constant.

9. The energy required by an electron to jump the forbidden band in silicon at room temperature is about

[1 mark]

- (A) 0.01 eV
(B) 0.05 eV
(C) 0.7 eV
(D) 1.1 eV

Correct Answer: (D) 1.1 eV

Solution:

Concept:

- The forbidden energy gap E_g is the separation between the valence-band maximum and the conduction-band minimum.
- An electron needs at least E_g to cross this gap; for silicon at room temperature, $E_g \simeq 1.1$ eV.

Step 1: Identify the material's band gap The electron must move from the valence band into the conduction band. Silicon has a room-temperature gap of approximately 1.1 eV, so this is the required

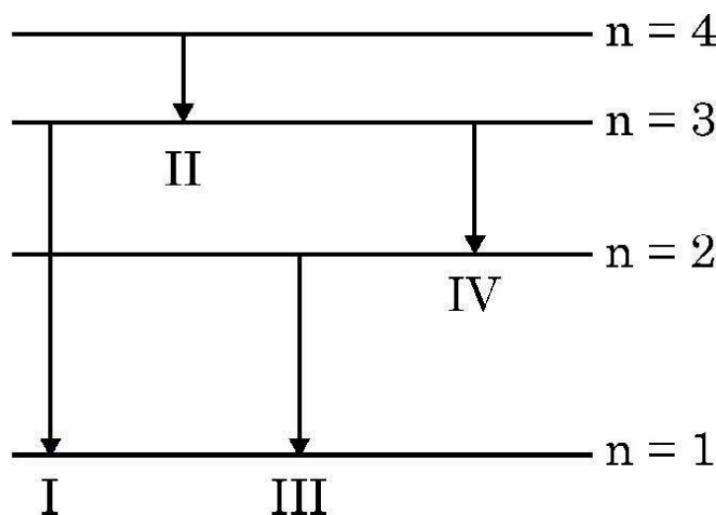
excitation energy.

Step 2: Check the other energy values The values 0.01 eV and 0.05 eV are much smaller than the silicon band gap. The value 0.7 eV is associated approximately with germanium's band gap, and must not be substituted for silicon's gap.

Step 3: Conclusion The required energy is about 1.1 eV. Hence, the correct option is (D).

Quick Tip to Solve: Remember the room-temperature pair: silicon about 1.1 eV, germanium about 0.7 eV.

10. The diagram shows four energy level of an electron in Bohr model of hydrogen atom. Identify the transition in which the emitted photon will have the highest energy. [1 mark]



- (A) I
- (B) II
- (C) III
- (D) IV

Correct Answer: (A) I

Solution:

Concept:

- Hydrogen energy levels are $E_n = -13.6/n^2$ eV, where n is the principal quantum number.
- For an emission from n_i to $n_f < n_i$, the photon energy is $E_\gamma = 13.6(1/n_f^2 - 1/n_i^2)$ eV.

Step 1: Read the four downward transitions In the printed diagram, I is $3 \rightarrow 1$, II is $4 \rightarrow 3$, III is $2 \rightarrow 1$, and IV is $3 \rightarrow 2$. Each downward arrow represents emission, so compare the differences in energy rather than merely the starting quantum numbers.

Step 2: Compare the photon energies Substitution into the energy-difference formula gives

$$\begin{aligned} E_I &= 13.6(1 - 1/9) \simeq 12.09 \text{ eV}, \\ E_{II} &= 13.6(1/9 - 1/16) \simeq 0.66 \text{ eV}, \\ E_{III} &= 13.6(1 - 1/4) = 10.20 \text{ eV}, \\ E_{IV} &= 13.6(1/4 - 1/9) \simeq 1.89 \text{ eV}. \end{aligned}$$

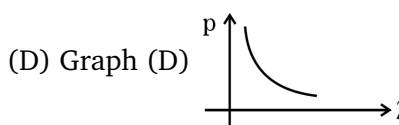
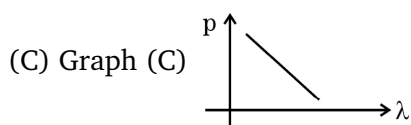
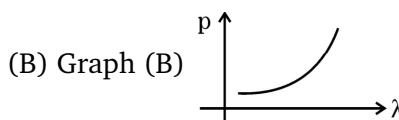
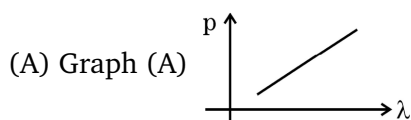
Transition II starts at the highest level but spans a small energy gap. Transition III ends at the ground

state but starts below I; IV also has a smaller gap.

Step 3: Conclusion Transition I, $n = 3 \rightarrow n = 1$, emits the highest-energy photon. Hence, the correct option is (A).

Quick Tip to Solve: Compare the initial and final levels together: among transitions ending at $n = 1$, the higher starting level gives more photon energy.

11. Which of the following graphs correctly represents the variation of a particle momentum with its associated de-Broglie wavelength? [1 mark]



Correct Answer: (D) Graph (D)



Solution:

Concept:

- The de Broglie relation is $\lambda = h/p$, where λ is wavelength, p is momentum magnitude and h is Planck's constant.
- Hence $p\lambda = h$: the graph of p against λ is a decreasing rectangular hyperbola in the positive quadrant.

Step 1: Determine how momentum changes Rearrange the relation to $p = h/\lambda$. Doubling the wavelength halves the momentum; increasing wavelength therefore decreases momentum nonlinearly. The slope is $-h/\lambda^2$, becoming less steep as wavelength increases.

Step 2: Test the printed graphs Graphs (A) and (B) increase with wavelength, contradicting inverse proportionality. Graph (C) decreases in a straight line, whereas the product $p\lambda$ must remain constant. Graph (D) decreases with progressively smaller slope magnitude and approaches the axes, as required by the de Broglie relation.

Step 3: Conclusion Graph (D) correctly represents $p = h/\lambda$. Hence, the correct option is (D).

Quick Tip to Solve: A decreasing straight line is not an inverse relation: for $p\lambda = h$, look for a decreasing hyperbola.

12. The capacitors, each of $4\ \mu\text{F}$ are to be connected in such a way that the effective capacitance of the combination is $6\ \mu\text{F}$. This can be achieved by connecting [1 mark]

- (A) All three in parallel
- (B) All three in series
- (C) Two of them connected in series and the combination in parallel to the third.
- (D) Two of them connected in parallel and the combination in series to the third.

Correct Answer: (C) Two of them connected in series and the combination in parallel to the third.

Solution:

Concept:

- Capacitors in parallel add directly: $C_p = C_1 + C_2$, since their potential differences are equal.
- Capacitors in series obey $1/C_s = 1/C_1 + 1/C_2$; two equal capacitors of capacitance C have equivalent capacitance $C/2$.

Step 1: Test the mixed connection in option C Connect two $4\ \mu\text{F}$ capacitors in series. Their equivalent capacitance is

$$C_s = \frac{4 \times 4}{4 + 4} = 2\ \mu\text{F}.$$

Placing this pair in parallel with the remaining capacitor gives $C_{eq} = 2 + 4 = 6\ \mu\text{F}$, exactly the required value.

Step 2: Check the remaining arrangements All three in parallel give $12\ \mu\text{F}$, whereas all three in series give $4/3\ \mu\text{F}$. Two in parallel give $8\ \mu\text{F}$; placing that combination in series with the third gives $8 \times 4/(8 + 4) = 8/3\ \mu\text{F}$. Thus none of those arrangements gives the target capacitance.

Step 3: Conclusion Connect two capacitors in series and that combination in parallel with the third. Hence, the correct option is (C).

Quick Tip to Solve: For three equal capacitors, a series pair in parallel with the third gives $C/2 + C = 3C/2$.

13. What is the ratio of inductive and capacitive reactance in an ac circuit? [1 mark]

- (A) $\omega^2 LC$
- (B) LC^2
- (C) $\frac{LC}{\omega^2}$
- (D) $\omega^2 L$

Correct Answer: (A) $\omega^2 LC$

Solution:

Concept:

- Inductive reactance is $X_L = \omega L$, where L is inductance and ω is the angular frequency.
- Capacitive reactance is $X_C = 1/(\omega C)$, where C is capacitance. Both reactances are measured in ohms.

Step 1: Form the requested ratio The ratio of inductive to capacitive reactance means X_L/X_C , in the

order stated. Substitute their expressions and invert the denominator:

$$\frac{X_L}{X_C} = \frac{\omega L}{1/(\omega C)} = (\omega L)(\omega C) = \omega^2 LC.$$

Step 2: Check the frequency and dimensional dependence Increasing frequency raises X_L and lowers X_C , so their ratio must increase as the square of frequency. Option (B) has no frequency dependence, option (C) decreases with ω^2 , and option (D) omits capacitance. Only $\omega^2 LC$ is the correct dimensionless ratio.

Step 3: Conclusion The ratio is $X_L/X_C = \omega^2 LC$. Hence, the correct option is (A).

Quick Tip to Solve: Dividing by $X_C = 1/(\omega C)$ means multiplying by ωC ; retain both factors of ω .

14. In an interference experiment, third bright fringe is obtained at a point on the screen with a light of 700 nm. What should be the wavelength of the light source in order to obtain the fifth bright fringe at the same point? [1 mark]

- (A) 420 nm
- (B) 750 nm
- (C) 630 nm
- (D) 500 nm

Correct Answer: (A) 420 nm

Solution:

Concept:

- A bright interference fringe occurs when the path difference is $\Delta = m\lambda$, where m is the fringe order.
- At a fixed screen point in the same arrangement, the geometrical path difference remains fixed, so $m_1\lambda_1 = m_2\lambda_2$.

Step 1: Determine the fixed path difference For the third bright fringe, $m_1 = 3$ and $\lambda_1 = 700$ nm. Therefore the path difference at this point is

$$\Delta = 3 \times 700 = 2100 \text{ nm.}$$

Step 2: Apply the fifth-order condition To make this same point the fifth bright fringe, require $5\lambda_2 = 2100$ nm. Thus $\lambda_2 = (3/5) \times 700 = 420$ nm. The values 750, 630 and 500 nm would give fifth-order path differences of 3750, 3150 and 2500 nm, respectively, so none matches this point.

Step 3: Conclusion The new wavelength must be 420 nm. Hence, the correct option is (A).

Quick Tip to Solve: At the same screen point, keep $m\lambda$ constant: changing the order from 3 to 5 multiplies wavelength by 3/5.

15. The radius of the n^{th} orbit in Bohr model of hydrogen atom is proportional to

[1 mark]

- (A) n^2
- (B) $1/n^2$
- (C) n
- (D) $1/n$

Correct Answer: (A) n^2

Solution:

Concept:

- In a hydrogen atom, electrostatic attraction supplies centripetal force: $m_e v^2/r = k e^2/r^2$, with $k = 1/(4\pi\epsilon_0)$.
- Bohr's angular-momentum quantisation is $m_e v r = n\hbar$, where n is the principal quantum number and $\hbar = h/(2\pi)$.

Step 1: Eliminate the orbital speed From quantisation, $v = n\hbar/(m_e r)$. Substitute this into the force equation:

$$\frac{n^2 \hbar^2}{m_e r^3} = \frac{k e^2}{r^2}.$$

Rearrangement gives $r_n = n^2 \hbar^2 / (m_e k e^2)$, with every factor other than n^2 constant for hydrogen.

Step 2: Identify the dependence on orbit number Therefore $r_n = a_0 n^2$, where a_0 is the Bohr radius. In particular, $r_2 = 4r_1$, which rules out the linear option. The reciprocal options predict smaller radii for higher orbits and contradict the derived expression. Do not confuse radius with the energy magnitude, which varies as $1/n^2$.

Step 3: Conclusion The orbital radius is proportional to n^2 . Hence, the correct option is (A).

Quick Tip to Solve: Keep the Bohr scalings distinct: radius grows as n^2 , while the magnitude of the energy falls as $1/n^2$.

16. Assertion (A): The resistance of an intrinsic semiconductor decreases with increase in its temperature.

Reason (R): The number of conduction electrons as well as hole increase in an intrinsic semiconductor with rise in its temperature.

[1 mark]

- (A) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).
- (B) Both Assertion (A) and Reason (R) are true and (R) is NOT the correct explanation of (A).
- (C) Assertion (A) is true and Reason (R) is false.
- (D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).

Solution:

Concept:

- An intrinsic semiconductor contains equal concentrations of free electrons and holes, generated as electron-hole pairs by thermal excitation.
- Its conductivity is $\sigma = e(n\mu_e + p\mu_h)$, where n, p are carrier concentrations and μ_e, μ_h are their mobilities. Resistance for fixed dimensions is inversely proportional to conductivity.

Step 1: Evaluate the assertion An intrinsic semiconductor has a negative temperature coefficient of resistance: raising its temperature increases conductivity and decreases resistance. Thus Assertion (A) is true.

Step 2: Evaluate the reason Heating supplies energy that excites more valence electrons across the forbidden gap into the conduction band. Each excitation leaves a hole, so the numbers of both conduction electrons and holes rise together. Reason (R) is therefore true.

Step 3: Test the explanatory connection The increase in thermally generated carriers dominates the reduction in their mobility over the intrinsic operating range. The resulting increase in conductivity explains the decrease in resistance. Thus R explains A, excluding option (B); options (C) and (D) incorrectly call the reason false.

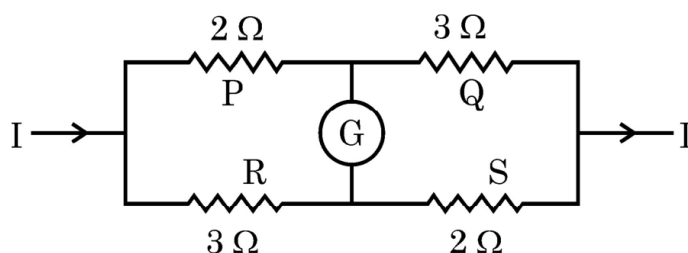
Step 4: Conclusion Both the assertion and reason are true, and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: In an intrinsic semiconductor, heating creates electron-hole pairs; the extra mobile carriers reduce resistance.

17. Assertion (A): The given figure does not show a balanced Wheatstone bridge.

Reason (R): For a balanced bridge small current should flow through the galvanometer.

[1 mark]



(A) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).

(B) Both Assertion (A) and Reason (R) are true and (R) is NOT the correct explanation of (A).

(C) Assertion (A) is true and Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (C) Assertion (A) is true and Reason (R) is false.

Solution:

Concept:

- A Wheatstone bridge is balanced when the arm resistances satisfy $P/Q = R/S$, with the galvanometer joining the two intermediate junctions.
- At balance these junctions have equal potential, so the galvanometer current is exactly zero.

Step 1: Test the assertion using the arm ratios The upper arms are $P = 2\ \Omega$ and $Q = 3\ \Omega$; the lower arms are $R = 3\ \Omega$ and $S = 2\ \Omega$. Thus

$$\frac{P}{Q} = \frac{2}{3} \neq \frac{3}{2} = \frac{R}{S}.$$

The bridge is unbalanced, so Assertion (A) is true. Equal total resistance in the two branches does not imply equal potentials at their intermediate junctions.

Step 2: Test the reason Reason (R) requires a small current at balance, whereas the defining condition

is no current through the galvanometer. A small nonzero current still indicates imbalance. Hence R is false.

Step 3: Check the explanation and options A false reason cannot explain the true assertion. Options (A) and (B) require a true reason, and option (D) requires a false assertion; all three are excluded.

Step 4: Conclusion The assertion is true and the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: Compare the ratios of corresponding arms, not their sums; balance always requires zero galvanometer current.

18. Assertion (A): The deflecting torque acting on a current carrying loop is zero when its plane is perpendicular to the direction of magnetic field.

Reason (R): The deflecting torque acting on a loop of magnetic moment $\vec{m}$ in a magnetic field $\vec{B}$ is given by the dot product of $\vec{m}$ and $\vec{B}$. [1 mark]

- (A) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).
(B) Both Assertion (A) and Reason (R) are true and (R) is NOT the correct explanation of (A).
(C) Assertion (A) is true and Reason (R) is false.
(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (C) Assertion (A) is true and Reason (R) is false.

Solution:

Concept:

- The magnetic moment $\vec{m}$ of a planar current loop is normal to its plane, with magnitude $m = NIA$, where N , I and A are the number of turns, current and area.
- Magnetic torque is $\vec{\tau} = \vec{m} \times \vec{B}$, of magnitude $mB \sin \theta$, where θ is the angle between the normal and the magnetic field.

Step 1: Evaluate the assertion When the plane is perpendicular to the field, its normal is parallel or antiparallel to $\vec{B}$. Thus $\theta = 0^\circ$ or 180° , and $\tau = mB \sin \theta = 0$. The assertion is true.

Step 2: Evaluate the reason Torque is the vector cross product, not the scalar dot product stated in the reason. The dot product instead enters magnetic potential energy, $U = -\vec{m} \cdot \vec{B}$. The reason is false.

Step 3: Assess the proposed explanation The false dot-product statement cannot explain the true assertion. Options (A) and (B) incorrectly make the reason true, while option (D) incorrectly makes the assertion false.

Step 4: Conclusion The assertion is true and the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: Measure the torque angle from the loop's normal; a plane perpendicular to the field gives zero torque.

Section B (14 marks)

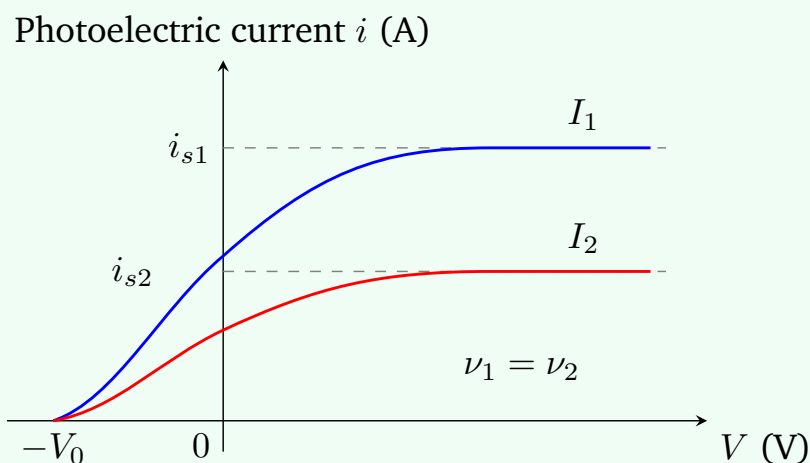
19. Plot a graph showing the variation of photo electric current, as a function of anode potential for two light beams having the same frequency but different intensities I_1 and I_2 ($I_1 > I_2$). Mention its important features. [2 marks]

Solution:

Concept:

- Photoelectric saturation current is proportional to incident intensity: a brighter beam of fixed frequency ejects more electrons per second.
- Einstein's equation gives $eV_0 = K_{\max} = h\nu - \phi$, where V_0 is the stopping-potential magnitude, ν is frequency and ϕ is the work function.

Step 1: Plot the two current curves Take anode potential relative to the cathode on the horizontal axis and photoelectric current on the vertical axis. Both beams have the same frequency above threshold. Since the printed intensities obey $I_1 > I_2$, the curve for I_1 reaches a higher saturation current than the curve for I_2 . Both curves meet the potential axis at the same negative potential $-V_0$.



Equal stopping potentials and unequal saturation currents for $I_1 > I_2$.

Step 2: Explain the important features Increasing positive anode potential collects a larger fraction of the emitted electrons, so current rises and then saturates when all emitted photoelectrons are collected. The saturation currents satisfy $i_{s1}/i_{s2} = I_1/I_2 > 1$. A finite current can flow even at zero anode potential because emitted electrons possess initial kinetic energy. A negative anode potential retards them; the current becomes zero at $-V_0$. Equal frequencies give equal maximum kinetic energies and hence the same stopping potential, independently of intensity.

Step 3: Conclusion The higher-intensity beam I_1 has the higher saturation current, while both beams have the same stopping-potential magnitude V_0 .

Quick Tip to Solve: For equal frequencies, align the negative-axis intercepts; use the intensity inequality only to order the saturation levels.

20(a). How will the De Broglie wavelength associated with an electron be affected when the (i) velocity of the electron decreases? and (ii) accelerating potential is increased? Justify your answer.

[2 marks]

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is the magnitude of electron momentum.
- For a nonrelativistic electron, $p = m_e v$; acceleration from rest through a potential difference V supplies kinetic energy $eV = p^2/(2m_e)$.

Step 1: Relate wavelength to electron speed For the same electron, m_e and h are constant, so

$$\lambda = \frac{h}{m_e v} \Rightarrow \lambda \propto \frac{1}{v}.$$

Therefore, decreasing the electron's speed decreases its momentum and increases its de Broglie wavelength. For two speeds, $\lambda_2/\lambda_1 = v_1/v_2$; for example, halving the speed doubles the wavelength in this approximation.

Step 2: Relate wavelength to accelerating potential An electron accelerated from rest gains energy eV , where e is the positive magnitude of its charge. Hence

$$p = \sqrt{2m_e eV}, \quad \lambda = \frac{h}{\sqrt{2m_e eV}} \propto V^{-1/2}.$$

Increasing the accelerating potential increases the electron's kinetic energy and momentum, so its wavelength decreases. In particular, $\lambda_2/\lambda_1 = \sqrt{V_1/V_2}$, so four times the potential gives half the wavelength.

Step 3: Conclusion (i) Decreasing electron speed increases its wavelength. (ii) Increasing accelerating potential decreases its wavelength, with $\lambda \propto V^{-1/2}$ in the nonrelativistic regime.

Quick Tip to Solve: Use $\lambda \propto 1/v$ for speed changes, but $\lambda \propto 1/\sqrt{V}$ for accelerating-potential changes.

OR

20(b). How would the stopping potential for a given photosensitive surface change if (i) the frequency of the incident radiation were increased? and (ii) the intensity of incident radiation were decreased? Justify your answer.

[2 marks]

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where ν is the incident frequency and ϕ is the fixed surface's work function.
- The stopping-potential magnitude V_0 satisfies $eV_0 = K_{\max}$, with e the magnitude of the electron charge. It measures the maximum emitted-electron energy.

Step 1: Increase the incident frequency For the given surface, ϕ is constant. Thus

$$V_0 = \frac{h\nu - \phi}{e}, \quad \Delta V_0 = \frac{h}{e} \Delta \nu.$$

Increasing frequency increases each photon's energy $h\nu$. After overcoming the same work function, more energy is available as maximum electron kinetic energy. The stopping-potential magnitude therefore increases; the required retarding anode potential becomes more negative.

Step 2: Decrease the incident intensity With frequency unchanged and above threshold, decreasing the intensity reduces the number of photons incident per second, without changing the energy of an individual photon. Fewer photoelectrons are emitted per second, so the photocurrent decreases. However, their maximum kinetic energy $h\nu - \phi$ is unchanged, and hence the stopping-potential magnitude is unchanged. This assumes a nonzero beam so photoemission can still be observed.

Step 3: Conclusion (i) Increasing frequency increases the stopping-potential magnitude. (ii) Decreasing intensity at fixed frequency leaves the stopping potential unchanged, although it reduces photocurrent.

Quick Tip to Solve: Use frequency to decide stopping potential and intensity to decide photocurrent; do not confuse photon energy with photon number.

21. How are electromagnetic waves produced? Write their two characteristics.

[2 marks]

Solution:

Concept:

- Electromagnetic radiation is produced by accelerating electric charges; an oscillating charge is a familiar example.
- A changing electric field and a changing magnetic field sustain a disturbance that travels through space.

Step 1: Explain the production of the wave When a charge oscillates, its velocity changes continuously, so it accelerates. The changing electric field associated with it produces a changing magnetic field, which in turn is associated with a changing electric field. This coupled disturbance propagates away from the source as an electromagnetic wave. A stationary charge produces only an electrostatic field.

Step 2: State two characteristics First, electromagnetic waves are transverse: the electric field and magnetic field are perpendicular to each other and to the direction of propagation. Their propagation direction is along $\vec{E} \times \vec{B}$. Second, they require no material medium and propagate in vacuum with speed

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.0 \times 10^8 \text{ m s}^{-1}.$$

Here μ_0 and ϵ_0 are the permeability and permittivity of vacuum.

Step 3: Conclusion Accelerated charges produce electromagnetic waves. These waves are transverse and can travel through vacuum at the speed of light.

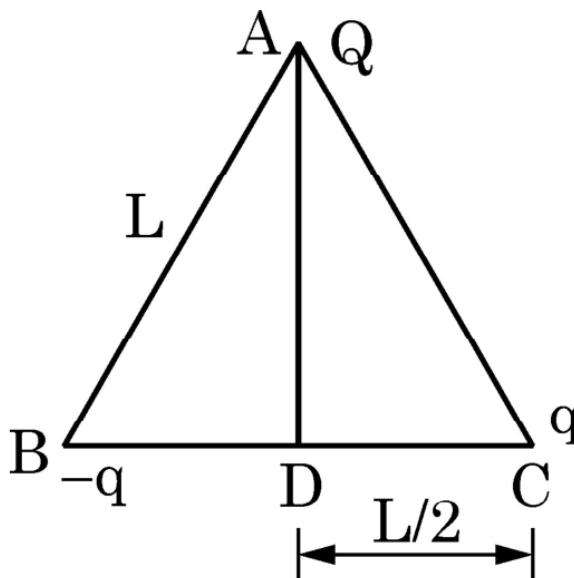
Quick Tip to Solve: Link production to acceleration, then give one field-direction property and one vacuum-propagation property.

22. Three point charges Q , q and $-q$ are kept at the vertices of an equilateral triangle of side L as shown in figure. What is

(i) the electrostatic potential energy of the arrangement? and

(ii) the potential at point D?

[2 marks]



Solution:

Concept:

- The potential energy of separated point charges is the sum over distinct pairs: $U = k \sum_{i < j} q_i q_j / r_{ij}$, with $k = 1/(4\pi\epsilon_0)$ and zero energy at infinite separation.
- Electric potential is a scalar sum, $V = k \sum_i q_i / r_i$; retain the algebraic sign of each source charge.

Step 1: Add the three pair energies All three sides of the equilateral triangle have length L . The pairs are $(Q, -q)$, (Q, q) , and $(-q, q)$. Each pair must be counted once:

$$U = k \left[\frac{-Qq}{L} + \frac{Qq}{L} + \frac{-q^2}{L} \right].$$

The two terms involving Q cancel because their separations are equal and the other charges are opposite. The remaining contribution is the negative interaction energy of the unlike base charges.

Step 2: Find the distances from D and add potentials The diagram gives $DC = L/2$, so D is the midpoint of BC and $DB = L/2$. The altitude of the equilateral triangle is

$$AD = \sqrt{L^2 - (L/2)^2} = \frac{\sqrt{3}L}{2}.$$

Hence the potential at D, taking zero potential at infinity, is

$$V_D = k \left[\frac{Q}{\sqrt{3}L/2} - \frac{q}{L/2} + \frac{q}{L/2} \right].$$

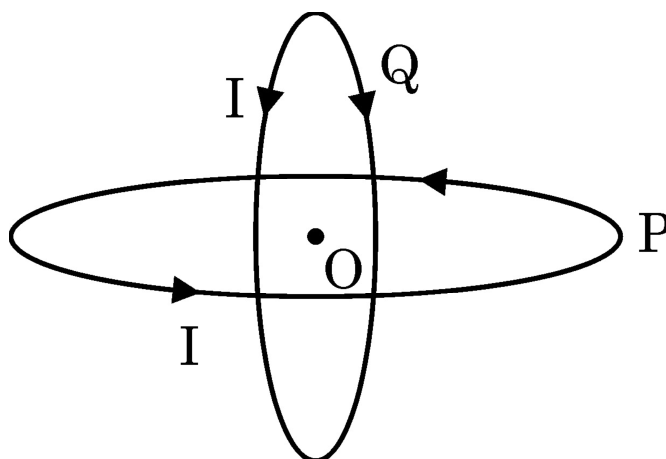
The potentials due to the base charges cancel; their electric fields need not cancel because fields are vectors.

Step 3: Conclusion (i) $U = -\frac{q^2}{4\pi\epsilon_0 L}$.

$$(ii) V_D = \frac{1}{4\pi\epsilon_0} \frac{2Q}{\sqrt{3}L}.$$

Quick Tip to Solve: Count three distinct charge pairs for energy; at the midpoint D, cancel the equal-distance opposite-charge potentials first.

23(a). Two identical circular loops P and Q, each of radius R carrying current I are kept in perpendicular planes such that they have a common centre O as shown in the figure. Find the magnitude and direction of the net magnetic field at the point O . [2 marks]



Solution:

Concept:

- The magnetic field at the centre of a circular loop of radius R carrying current I is $B_0 = \mu_0 I / (2R)$, directed along its normal by the right-hand thumb rule.
- Magnetic fields add vectorially. Normals to perpendicular loop planes are perpendicular, so these two fields must be combined using the perpendicular-vector resultant.

Step 1: Identify the two component fields Since the loops are identical and carry equal currents, their fields at the common centre have the same magnitude:

$$B_P = B_Q = B_0 = \frac{\mu_0 I}{2R}.$$

Let $\hat{n}_P$ and $\hat{n}_Q$ denote the normals in the field directions selected by curling the right-hand fingers along each loop's current. The thumb points along that loop's field. The perpendicular planes imply $\hat{n}_P \cdot \hat{n}_Q = 0$.

Step 2: Add the perpendicular fields and determine the direction The vector resultant and its magnitude are

$$\vec{B} = \frac{\mu_0 I}{2R} (\hat{n}_P + \hat{n}_Q), \quad B = \sqrt{B_P^2 + B_Q^2}.$$

If θ is the angle the resultant makes with $\vec{B}_P$, then $\tan \theta = B_Q / B_P = 1$. It therefore lies along the

internal bisector of the two magnetic-field vectors, in the plane containing both normals. Adding the magnitudes directly would incorrectly treat the fields as parallel.

Step 3: Conclusion $B = \frac{\mu_0 I}{\sqrt{2}R}$. The net field makes 45° with each loop's field direction (the corresponding normals selected by the right-hand rule), along $\hat{n}_P + \hat{n}_Q$.

Quick Tip to Solve: Equal fields along perpendicular loop axes give a resultant $\sqrt{2}$ times either field, directed along their internal bisector.

OR

23(b). A long straight conductor kept along $X'X$ axis, carries a steady current I along $+x$ direction. At an instant t , a particle of mass m and charge q at point (x, y) moves with a velocity $\vec{v}$ along $+y$ direction. Find the magnitude and direction of the force on the particle due to the conductor. [2 marks]

Solution:

Concept:

- At perpendicular distance r from a long straight wire, $B = \mu_0 I / (2\pi r)$; its direction follows the right-hand thumb rule about the current.
- The magnetic force on a charge is $\vec{F} = q\vec{v} \times \vec{B}$. Its direction reverses when the charge sign reverses.

Step 1: Find the magnetic field at the particle The wire lies along the x -axis, so the perpendicular distance of the point (x, y) is $|y|$, not its distance from the origin. Choose $+z$ perpendicular out of the xy -plane. For current along $+x$, the right-hand rule gives field along $+z$ when $y > 0$ and along $-z$ when $y < 0$. Thus, for $y \neq 0$,

$$\vec{B} = \frac{\mu_0 I}{2\pi y} \hat{z}.$$

The signed denominator records both cases; the field magnitude uses $|y|$.

Step 2: Use the vector magnetic-force law With $\vec{v} = v\hat{y}$, the velocity is perpendicular to the magnetic field. Since $\hat{y} \times \hat{z} = \hat{x}$,

$$\vec{F} = qv\hat{y} \times \frac{\mu_0 I}{2\pi y} \hat{z} = \frac{\mu_0 Iqv}{2\pi y} \hat{x}.$$

Hence a positive charge above the wire experiences force along $+x$. A negative charge there experiences force along $-x$; crossing to the other side of the wire also reverses the direction. The mass m is unnecessary for the force, although it would enter the acceleration.

Step 3: Conclusion $F = \frac{\mu_0 I|q|v}{2\pi|y|}$, with $\vec{F} = \frac{\mu_0 Iqv}{2\pi y} \hat{x}$. For $q > 0$, $y > 0$, the force is along $+x$; the sign of q/y sets the general direction.

Quick Tip to Solve: Measure distance from the wire as $|y|$, then use $\hat{y} \times \hat{z} = \hat{x}$ and apply the charge sign last.

24. Two conductors, made of the same material have equal lengths but different cross-sectional areas A_1 and A_2 ($A_1 > A_2$). They are connected in parallel across a cell. Show that the drift velocities of electrons in two conductors are equal. [2 marks]

Solution:

Concept:

- A uniform conductor has resistance $R = \rho\ell/A$, where ρ is resistivity, ℓ its length and A its cross-sectional area.
- The current magnitude is $I = neAv_d$, where n is the free-electron number density, e the electronic charge magnitude and v_d the electron drift speed.

Step 1: Compare the currents through the parallel conductors Let V be the common potential difference across the parallel branches and ℓ their equal length. At the same temperature, the same material gives the same ρ and n . Ohm's law gives

$$R_1 = \frac{\rho\ell}{A_1}, \quad R_2 = \frac{\rho\ell}{A_2}, \quad I_1 = \frac{VA_1}{\rho\ell}, \quad I_2 = \frac{VA_2}{\rho\ell}.$$

Therefore the wider conductor carries more current in exactly the ratio of the areas: $I_1/I_2 = A_1/A_2$.

Step 2: Divide each current by its carrier factor Using $v_d = I/(neA)$ in the two branches,

$$v_{d1} = \frac{VA_1}{\rho\ell} \frac{1}{neA_1} = \frac{V}{ne\rho\ell},$$
$$v_{d2} = \frac{VA_2}{\rho\ell} \frac{1}{neA_2} = \frac{V}{ne\rho\ell}.$$

The area cancels because a larger area increases both current and the number of carriers crossing a section in the same proportion. Electrons drift opposite to the electric field in each branch.

Step 3: Conclusion $v_{d1} = v_{d2} = \frac{V}{ne\rho\ell}$. Thus the electron drift speeds are equal despite $A_1 > A_2$, since the branches have the same material, length and applied potential difference.

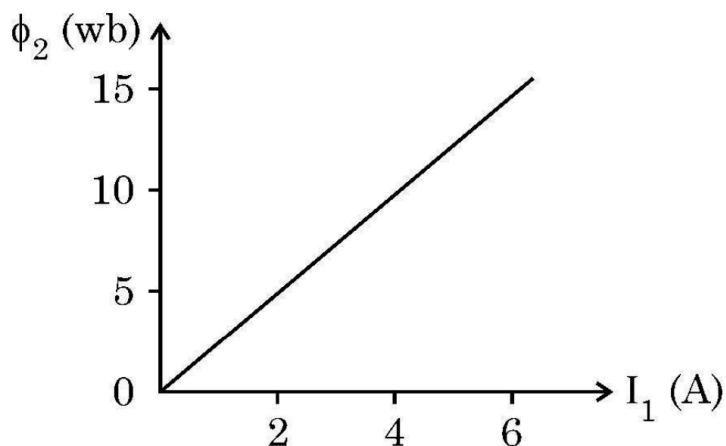
Quick Tip to Solve: In equal-length parallel wires, first use $I \propto A$; this area factor cancels in $v_d = I/(neA)$.

25. Two coils C_1 and C_2 are placed close to each other. The magnetic flux ϕ_2 linked with the coil C_2 varies with the current I_1 flowing in coil C_1 , as shown in the figure. Find

(i) the mutual inductance of the arrangement, and

(ii) the rate of change of current $\left(\frac{dI_1}{dt}\right)$ that will induce an emf of 100 V in coil C_2 .

[2 marks]



Solution:

Concept:

- Mutual inductance M is the flux linkage in the secondary coil per unit primary current: $\phi_2 = MI_1$. Its SI unit is henry (H).
- The induced emf obeys $\varepsilon_2 = -M dI_1/dt$; the minus sign expresses Lenz's law. For its magnitude, use $|\varepsilon_2| = M|dI_1/dt|$.

Step 1: (i) Read the slope of the graph The straight line passes through the origin and the point corresponding to $I_1 = 6$ A, $\phi_2 = 15$ Wb. Since flux linkage is on the vertical axis and current on the horizontal axis, its slope gives the mutual inductance:

$$M = \frac{\Delta\phi_2}{\Delta I_1} = \frac{15 - 0}{6 - 0} = 2.5 \text{ Wb A}^{-1} = 2.5 \text{ H}.$$

The constant slope shows that this value is independent of current over the plotted range.

Step 2: (ii) Apply the induced-emf relation For an induced emf of magnitude 100 V, divide the required emf by the mutual inductance:

$$\left|\frac{dI_1}{dt}\right| = \frac{|\varepsilon_2|}{M} = \frac{100}{2.5} = 40 \text{ A s}^{-1}.$$

The graph fixes the magnitude. Whether the current increases or decreases determines the polarity of the induced emf, which always opposes the change in linked flux.

Step 3: Conclusion (i) The mutual inductance is 2.5 H. (ii) The required rate of change of current has magnitude 40 A s^{-1} .

Quick Tip to Solve: Read the slope as flux divided by current, then divide the required emf by that slope; do not invert the graph's axes.

Section C (15 marks)

26(a). A plane wave-front propagating in a medium of refractive index ' μ_1 ' is incident on a plane surface making an angle of incidence (i). It enters into a medium of refractive index μ_2 ($\mu_2 > \mu_1$). Use Huygen's construction of secondary wavelets to trace the refracted wave-front. Hence verify Snell's law of refraction. [3 marks]

Solution:

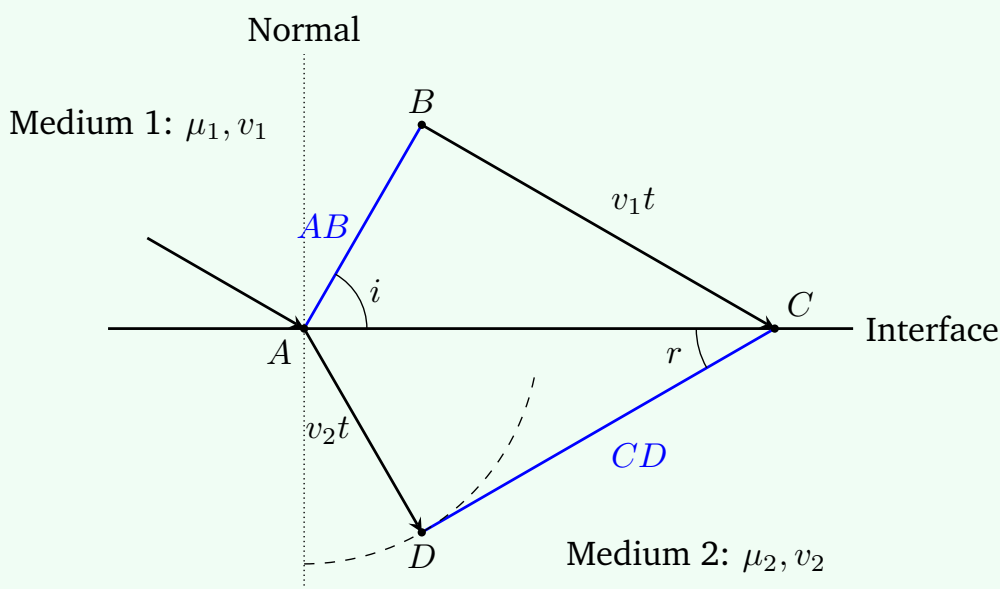
Concept:

- Each point of a wavefront emits secondary wavelets. The forward common tangent to these wavelets gives the new wavefront.
- In a medium of refractive index μ , light travels at speed $v = c/\mu$. Rays are perpendicular to wavefronts, so the angle between a wavefront and the interface equals the corresponding ray angle with the normal.

Step 1: Construct the refracted wavefront Let AB be the incident plane wavefront and AC the interface. Point A reaches the interface first. While the disturbance at B travels to C in time t , the secondary wavelet from A advances into the second medium through distance AD . Thus

$$BC = v_1 t, \quad AD = v_2 t.$$

With A as centre and $v_2 t$ as radius, draw a secondary wavelet in medium 2. The tangent drawn from C touches it at D . The line CD is the refracted plane wavefront, and AD , perpendicular to CD , is a refracted ray. Wavelets from the intermediate points on the interface share this forward tangent. Since $\mu_2 > \mu_1$, we have $v_2 < v_1$, hence $AD < BC$.



Huygens construction: AB is incident and CD is refracted; the dashed arc is the secondary wavelet from A .

Step 2: Relate the angles to the travelled distances The incident ray BC is perpendicular to AB , while the radius AD is perpendicular to its tangent CD . Hence ABC and ADC are right triangles with common hypotenuse AC . The wavefront angles $\angle BAC = i$ and $\angle ACD = r$ equal the ray angles with the normal. Therefore

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}, \quad \sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}.$$

Step 3: Verify Snell's law Dividing these equations cancels both the common time and the common hypotenuse:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{c/\mu_1}{c/\mu_2} = \frac{\mu_2}{\mu_1}.$$

The construction also places the incident ray, refracted ray and interface normal in the same plane.

Step 4: Conclusion The tangent CD is the refracted wavefront and $\mu_1 \sin i = \mu_2 \sin r$, verifying Snell's law. Since $\mu_2 > \mu_1$, $r < i$: the ray bends towards the normal.

Quick Tip to Solve: Use the same time for both distances, then divide the sine ratios of the two right triangles sharing the interface segment AC .

OR

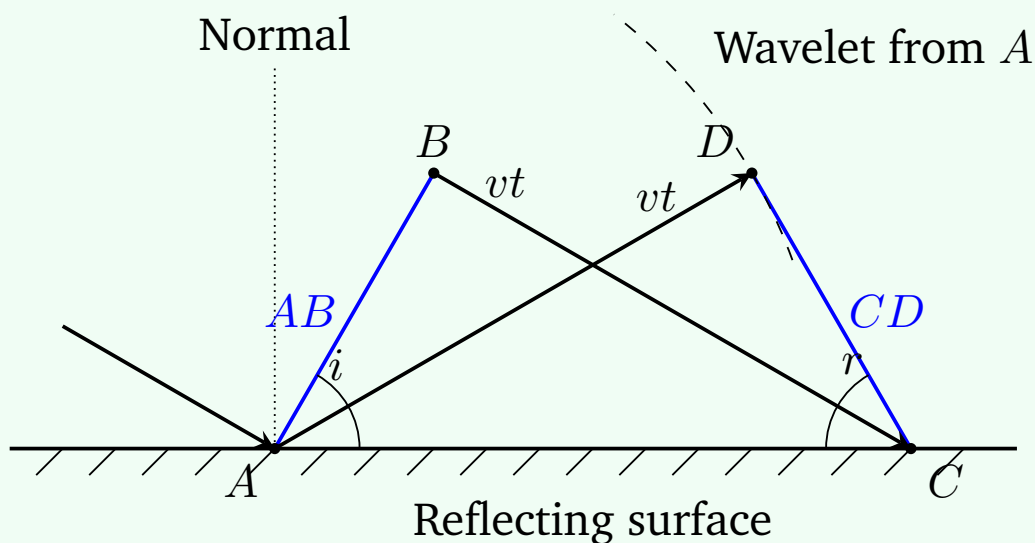
26(b). Using Huygen's construction, show how a plane wave is reflected from a surface. Hence verify the law of reflection. [3 marks]

Solution:

Concept:

- Huygens' principle treats each point of a wavefront as a source of secondary wavelets. Their forward common tangent is the subsequent wavefront.
- A ray is normal to its wavefront. Reflection occurs in the same medium, so incident and reflected disturbances have the same speed v .

Step 1: Form the reflected wavefront Let AB be an incident plane wavefront approaching the reflecting surface AC . Point A touches the surface first and begins sending a secondary wavelet back into the incident medium. During time t , the disturbance at B reaches C , travelling the distance $BC = vt$. In the same time the reflected secondary wavelet from A acquires radius $AD = vt$. Draw this wavelet centred at A , then draw its tangent from C , touching at D . The tangent CD is the reflected plane wavefront, since it is the common envelope of the reflected wavelets from all intermediate points. The line AD , normal to CD , gives the reflected-ray direction.



Reflection construction: AB and CD are the incident and reflected wavefronts; BC and AD both equal vt .

Step 2: Compare the two right triangles Since BC is an incident ray, $AB \perp BC$. The radius at the point of tangency satisfies $AD \perp CD$. Thus triangles ABC and ADC are right triangles, having common hypotenuse AC and equal sides $BC = AD = vt$. They are congruent by the right-angle, hypotenuse and side criterion. Alternatively, the wavefront angles obey

$$\sin \angle BAC = \frac{BC}{AC}, \quad \sin \angle ACD = \frac{AD}{AC}.$$

Their equality follows directly from $BC = AD$.

Step 3: Identify the incidence and reflection angles Because rays are perpendicular to wavefronts and the normal is perpendicular to the surface, $\angle BAC = i$, the angle of incidence, and $\angle ACD = r$, the angle of reflection. Hence

$$\sin i = \sin r \Rightarrow i = r,$$

for the physical angles between 0° and 90° . The construction lies in the plane containing the incident ray and normal, so the reflected ray is also in that plane.

Step 4: Conclusion The tangent CD represents the reflected wavefront. Huygens' construction gives $i = r$, with the incident ray, reflected ray and normal lying in the same plane, verifying the laws of reflection.

Quick Tip to Solve: For reflection the two travelled distances BC and AD are equal because both waves move in the same medium for the same time.

27. An alternating current $I = 14 \sin(100\pi t)$ A passes through a series combination of a resistor of 30Ω and an inductor of $\left(\frac{2}{5\pi}\right)$ H. Taking $\sqrt{2} = 1.4$, calculate the

- (i) rms value of the voltage drops across the resistor and the inductor, and
(ii) power factor of the circuit.

[3 marks]

Solution:

Concept:

- For a sinusoidal current $I = I_0 \sin \omega t$, the rms current is $I_{\text{rms}} = I_0/\sqrt{2}$. Here I_0 is peak current and ω is angular frequency.
- An ideal inductor has reactance $X_L = \omega L$. In a series RL circuit, $V_R = I_{\text{rms}}R$, $V_L = I_{\text{rms}}X_L$, and impedance $Z = \sqrt{R^2 + X_L^2}$.
- The power factor is $\cos \phi = R/Z$, where ϕ is the phase by which current lags the applied voltage.

Step 1: Identify the current and reactance Comparing the given current $I = 14 \sin(100\pi t)$ A with the standard form gives $I_0 = 14$ A and $\omega = 100\pi$ rad s^{-1} . Using the specified approximation $\sqrt{2} = 1.4$,

$$I_{\text{rms}} = \frac{14}{1.4} = 10 \text{ A}.$$

The inductor's reactance is

$$X_L = \omega L = (100\pi) \left(\frac{2}{5\pi}\right) = 40 \Omega.$$

The coefficient of time is already angular frequency, so no additional factor of 2π is required.

Step 2: (i) Find the rms voltage across each component The same rms current flows through both

components because they are in series. Apply the corresponding resistance or reactance to each:

$$V_R = I_{\text{rms}}R = 10 \times 30 = 300 \text{ V},$$
$$V_L = I_{\text{rms}}X_L = 10 \times 40 = 400 \text{ V}.$$

The resistor voltage is in phase with the current; the inductor voltage leads the current by 90° . Thus these component voltages are perpendicular phasors and cannot be added as ordinary scalar magnitudes.

Step 3: (ii) Calculate the power factor The impedance is the magnitude of the vector combination of resistance and inductive reactance:

$$Z = \sqrt{30^2 + 40^2} = \sqrt{2500} = 50 \Omega.$$

Therefore

$$\cos \phi = \frac{R}{Z} = \frac{30}{50} = 0.60.$$

The power factor is lagging because the net reactance is inductive. As a check, the supply rms voltage is $I_{\text{rms}}Z = 500 \text{ V}$, and $V_R/V = 300/500 = 0.60$.

Step 4: Conclusion (i) The rms voltage drops are $V_R = 300 \text{ V}$ and $V_L = 400 \text{ V}$. (ii) The circuit has power factor 0.60, lagging.

Quick Tip to Solve: Convert the 14 A peak current to 10 A rms first; the 30-40-50 impedance triangle then gives the power factor immediately as 30/50.

28. State the basic principle behind the working of an ac generator. Briefly describe its working and obtain the expression for the instantaneous value of emf induced. [3 marks]

Solution:

Concept:

- An ac generator works on electromagnetic induction: an emf is induced whenever the magnetic flux linked with its coil changes.
- Faraday's law gives $\varepsilon = -d(N\Phi)/dt$, where N is the number of turns and Φ is the magnetic flux through one turn. The minus sign expresses Lenz's law.

Step 1: Describe the arrangement and rotation A rectangular armature coil of N turns and area A is rotated mechanically with constant angular speed ω in a uniform magnetic field B . The axis of rotation lies in the plane of the coil and is perpendicular to the field. The coil ends connect to two separate slip rings; stationary carbon brushes touching these rings connect the rotating coil to the external circuit. As the coil rotates, the angle between its area vector and the magnetic field changes, so the linked magnetic flux changes and an emf is induced. This converts mechanical energy into electrical energy.

Step 2: Express the flux linkage Choose $t = 0$ when the normal to the coil is parallel to the magnetic

field. After time t , the angle of this normal with the field is $\theta = \omega t$. Thus the flux through each turn and the total flux linkage are

$$\Phi = BA \cos \omega t, \quad N\Phi = NBA \cos \omega t.$$

Step 3: Differentiate to obtain the induced emf Applying Faraday's law to the changing flux linkage,

$$\begin{aligned} \varepsilon(t) &= -\frac{d}{dt}(NBA \cos \omega t) \\ &= NBA\omega \sin \omega t. \end{aligned}$$

The sine changes sign after every half-rotation, so the emf and, for a resistive load, the current reverse direction every half-cycle. The separate slip rings preserve this alternating output. The emf is zero when the flux is maximum and has maximum magnitude when the plane of the coil is parallel to the field.

Step 4: Conclusion An ac generator uses electromagnetic induction and produces $\varepsilon(t) = \varepsilon_0 \sin \omega t$, where the peak emf is $\varepsilon_0 = NBA\omega$. The chosen time origin sets the sine phase, and the frequency is $f = \omega/(2\pi)$.

Quick Tip to Solve: Measure the flux angle from the coil's normal: flux varies as cosine, while its negative time derivative, the emf, varies as sine.

- 29. (a) Briefly describe how the current sensitivity of a moving coil galvanometer can be increased.**
(b) A galvanometer shows full scale deflection for current I_g . A resistance R_1 is required to convert it into a voltmeter of range $(0 - V)$ and a resistance R_2 to convert it into a voltmeter of range $(0 - 2V)$. Find the resistance of the galvanometer. [3 marks]

Solution:

Concept:

- Current sensitivity is angular deflection per unit current: $S_I = \theta/I$. In a radial magnetic field, equilibrium of magnetic and restoring torques gives $NIAB = k\theta$.
- A galvanometer of resistance G and full-scale current I_g becomes a voltmeter by adding a high series resistance R . Its full-scale range obeys $V = I_g(G + R)$.

Step 1: (a) Obtain the current sensitivity Let N be the number of coil turns, A its area, B the radial magnetic field and k the restoring torque per unit angular twist of its suspension. At steady deflection the restoring torque balances the magnetic torque:

$$k\theta = NIAB \quad \Rightarrow \quad S_I = \frac{\theta}{I} = \frac{NAB}{k}.$$

Hence sensitivity can be increased by increasing the number of turns, increasing the coil area, using a stronger magnetic field, or reducing the torsional constant of the suspension. A soft-iron core helps provide a stronger radial field, while a suspension with small restoring torque produces greater deflection for the same current.

Step 2: (b) Write the two full-scale conditions The same galvanometer requires the same full-scale current I_g in both conversions. Since the added resistance is in series, the voltage range equals that

current times the total resistance. Therefore,

$$V = I_g(G + R_1), \quad 2V = I_g(G + R_2).$$

Here R_1 and R_2 are the added resistances, rather than the total instrument resistances. Keeping G in both equations is essential.

Step 3: Eliminate the current and voltage Divide the second full-scale condition by the first:

$$\frac{G + R_2}{G + R_1} = 2.$$

On expanding, $G + R_2 = 2G + 2R_1$. Transferring the terms gives the required expression for the internal resistance. Equivalently, subtracting the original equations first gives $V/I_g = R_2 - R_1$, which can be substituted into the first equation as a check.

Step 4: Conclusion (a) Increase N , A or B , or decrease k , to increase $S_I = NAB/k$. (b) The galvanometer resistance is $G = R_2 - 2R_1$. A positive internal resistance requires $R_2 > 2R_1$.

Quick Tip to Solve: For a doubled voltmeter range, double the total resistance $G + R_1$, not just the external series resistance R_1 .

30(a). Calculate the binding energy of an alpha particle in MeV. Given

mass of a proton = $1.007825 u$

mass of a neutron = $1.008665 u$

mass of He nucleus = $4.002800 u$

$1u = 931 \text{ MeV}/c^2$

[3 marks]

Solution:

Concept:

- Nuclear binding energy is the energy needed to separate a nucleus completely into its constituent free nucleons. It equals the mass defect multiplied by c^2 : $E_b = \Delta mc^2$.
- An alpha particle has two protons and two neutrons. Hence $\Delta m = 2m_p + 2m_n - m_\alpha$, using the masses supplied in the question.

Step 1: Identify the constituents and their total free mass The alpha particle is a helium nucleus with mass number four and atomic number two. Its constituent particles are therefore two protons and two neutrons. Using the printed mass values as supplied,

$$\begin{aligned} m_{\text{free}} &= 2(1.007825) + 2(1.008665) \\ &= 2.015650 + 2.017330 \\ &= 4.032980 u. \end{aligned}$$

These are the masses before the nucleons bind together, so they must be added before subtracting the given nuclear mass.

Step 2: Calculate the mass defect The bound nucleus has a smaller mass because energy is released

when it forms. The mass defect is the free-nucleon mass minus the bound-nucleus mass:

$$\begin{aligned}\Delta m &= 4.032980 - 4.002800 \\ &= 0.030180 \, u.\end{aligned}$$

Its positive sign is consistent with a bound nucleus. The numerical data are used exactly as stated in the paper; no replacement by other tabulated masses is needed.

Step 3: Convert the mass defect to energy The supplied conversion $1u = 931 \text{ MeV}/c^2$ means that a mass defect of $1u$ corresponds to 931 MeV of binding energy. Thus,

$$E_b = 0.030180 \times 931 = 28.09758 \text{ MeV}.$$

The factors of c^2 cancel between the mass unit conversion and Einstein's relation. This is the total energy for the alpha particle, so it is not divided by its four nucleons.

Step 4: Conclusion Using the masses given in the question, the binding energy of the alpha particle is

$$E_b \simeq 28.1 \text{ MeV}.$$

Quick Tip to Solve: For an alpha particle, add two proton and two neutron masses, subtract the supplied helium-nucleus mass, and multiply the defect in u by 931 .

OR

30(b). A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits into two nuclei Q and R of mass number 110 and 130 and binding energy per nucleon 8.5 MeV and 8.4 MeV respectively. Calculate the energy released in the fission. [3 marks]

Solution:

Concept:

- The total binding energy of a nucleus is its mass number multiplied by its binding energy per nucleon: $B = A(B/A)$.
- Energy released in fission equals the increase in total binding energy: $E_{\text{released}} = B_{\text{products}} - B_{\text{parent}}$. More tightly bound products have lower rest energy.

Step 1: Find the binding energy of the parent nucleus Nucleus P contains 240 nucleons, each contributing an average binding energy of 7.6 MeV . Its total binding energy is therefore

$$B_P = 240 \times 7.6 = 1824 \text{ MeV}.$$

Binding energy per nucleon is an average, so the mass number must multiply it before energies of different nuclei can be compared. Subtracting only the quoted per-nucleon values would ignore their unequal numbers of nucleons.

Step 2: Find the combined binding energy of the products The daughter nuclei have mass numbers 110 and 130. Their mass numbers add to $110 + 130 = 240$, consistent with the stated fission and with

no missing nucleons in the calculation. Their individual and combined binding energies are

$$\begin{aligned}B_Q &= 110 \times 8.5 = 935 \text{ MeV}, \\B_R &= 130 \times 8.4 = 1092 \text{ MeV}, \\B_Q + B_R &= 935 + 1092 = 2027 \text{ MeV}.\end{aligned}$$

Step 3: Calculate the increase in binding energy Conservation of energy makes the increase in nuclear binding energy available as energy released during fission:

$$\begin{aligned}E_{\text{released}} &= (B_Q + B_R) - B_P \\&= 2027 - 1824 \\&= 203 \text{ MeV}.\end{aligned}$$

The result is positive because the daughter nuclei are more tightly bound overall. This corresponds to a decrease in the total rest mass of the system; the freed energy appears mainly as kinetic energy of the fragments, with any accompanying radiation included in the energy balance.

Step 4: Conclusion The energy released in the fission of one nucleus P is 203 MeV.

Quick Tip to Solve: First multiply each binding energy per nucleon by its own mass number; then subtract the parent's total from the sum for the two daughters.

Section D (15 marks)

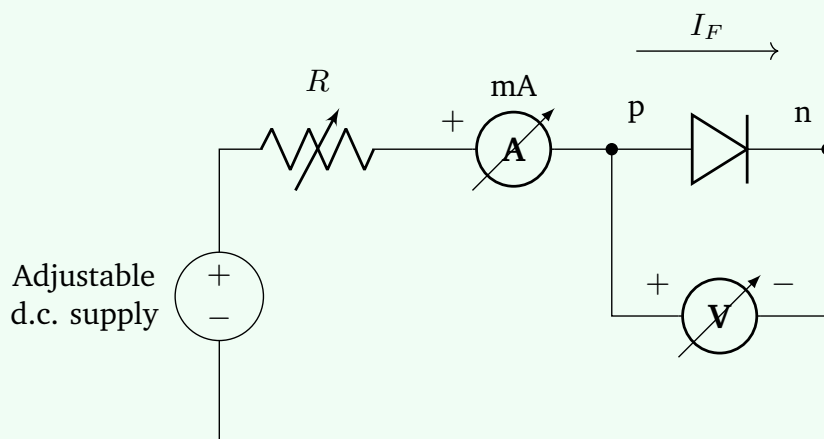
31(a). Draw the circuit arrangement for studying V-I characteristics of a p-n junction diode in (i) forward biasing and (ii) reverse biasing. Draw the typical V-I characteristics of a silicon diode. Describe briefly the following terms: (i) minority carrier injection in forward biasing and (ii) breakdown voltage in reverse biasing. [5 marks]

Solution:

Concept:

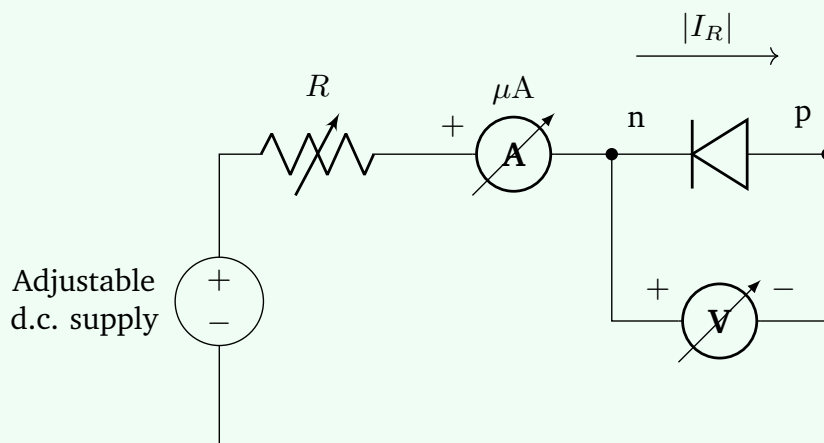
- The applied bias changes the depletion-layer width and potential barrier of a p-n junction. Forward bias lowers the barrier; reverse bias raises it.
- Measure the diode voltage with a voltmeter in parallel and its current with an ammeter in series. Use a milliammeter for forward current and a microammeter for the small reverse current.
- Majority carriers crossing the junction become minority carriers on the opposite side. Reverse breakdown produces a large reverse current at an approximately fixed reverse voltage.

Step 1: Connect the forward-bias circuit Connect the p-side (anode) to the positive terminal of an adjustable d.c. supply and the n-side (cathode) to its negative terminal. The series rheostat R limits and adjusts the current. Connect the positive terminals of the milliammeter and voltmeter towards the higher potential. Increase the supply in small steps and record the diode voltage V_F and forward current I_F . The voltmeter measures the voltage across the diode alone, not across the diode and resistor together.



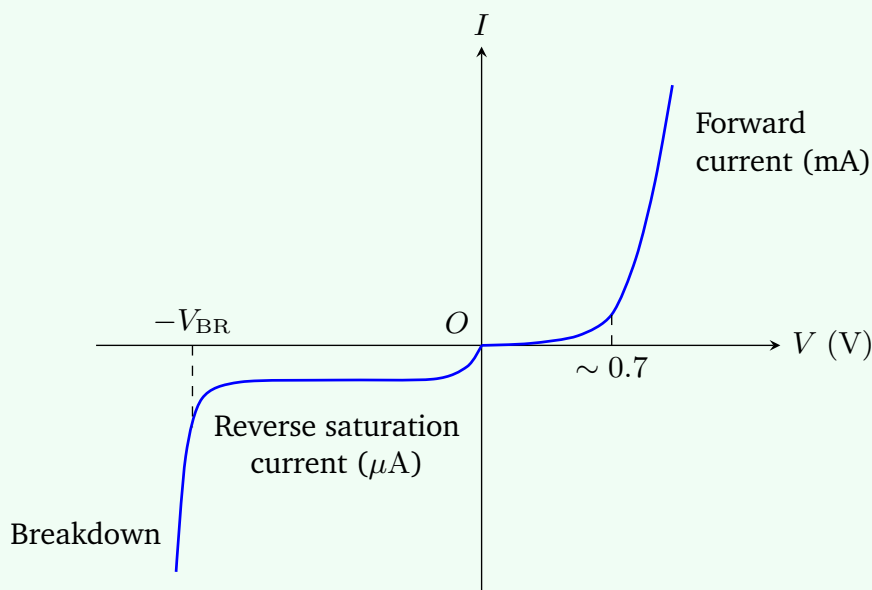
Forward bias: p at positive potential; mA in series and V across the diode.

Step 2: Connect the reverse-bias circuit Reverse the diode connections: connect n to the positive supply terminal and p to the negative terminal. Replace the milliammeter with a microammeter, because reverse current before breakdown is very small. Keep the voltmeter parallel to the diode with its positive terminal on n. Increase the reverse voltage gradually, recording V_R and I_R . The resistance limits the current; an ordinary diode must not be driven beyond its safe ratings while investigating breakdown.



Reverse bias: n at positive potential; use a microammeter in series.

Step 3: Sketch and interpret the silicon characteristic Take diode voltage $V = V_p - V_n$ horizontally and conventional diode current from p to n vertically. The forward current is initially small and rises rapidly beyond the knee, about 0.7 V for silicon. This is an approximate turn-on value, not an abrupt universal threshold. Under reverse bias the current is a small, nearly constant reverse saturation current due to minority carriers. At $V = -V_{BR}$, its magnitude rises sharply. The sketch uses different current scales for the forward and reverse regions; typical forward current is measured in milliamperes and reverse current in microamperes.



Typical silicon diode characteristic (schematic; forward and reverse scales differ).

Step 4: Explain minority carrier injection In forward bias the reduced potential barrier allows electrons, the majority carriers in the n-region, to diffuse into the p-region. There they are minority carriers. Similarly, holes from the p-region enter the n-region and become minority carriers there. This transport raises the minority-carrier concentration near each edge of the depletion layer above its equilibrium value and is called minority carrier injection. The injected carriers then diffuse farther into the neutral regions and recombine, while the external supply maintains the forward current.

Step 5: Define reverse breakdown voltage Breakdown voltage V_{BR} is the magnitude of the reverse bias at which the diode's reverse current suddenly increases greatly for a small further increase in voltage. The strong junction electric field causes Zener tunnelling or avalanche multiplication, depending on the junction. It is distinct from the forward knee voltage. A suitable series resistance is essential because excessive current can heat and damage a diode, even though breakdown itself can be reversible when the current is properly limited.

Step 6: Conclusion Forward bias connects p to positive and gives a rapidly increasing current beyond the silicon knee near 0.7 V; reverse bias connects n to positive and gives a small current until breakdown. Minority carrier injection is the entry of majority carriers into the opposite region as minority carriers, and V_{BR} is the reverse-voltage magnitude at the sharp current increase.

Quick Tip to Solve: Label p and n before connecting the supply: p-positive means forward bias. Put the voltmeter across the diode and change from mA to μ A when drawing the reverse-bias circuit.

31(b). Name two important processes involved in the formation of a p-n junction diode. With the help of a circuit diagram, explain the working of junction diode as a full wave rectifier. Draw its input and output waveforms. State the characteristic property of a junction diode that makes it suitable for rectification. [5 marks]

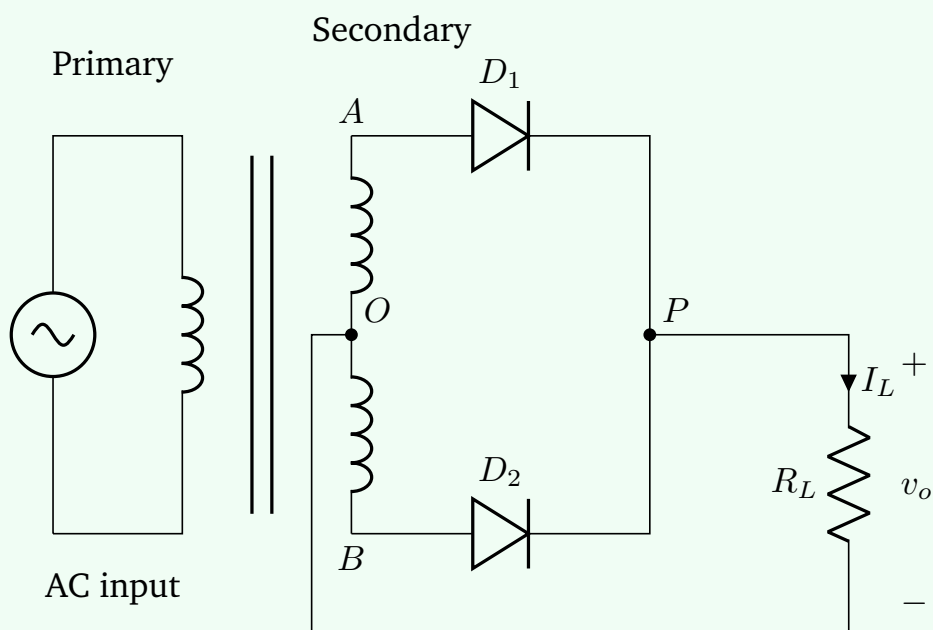
Solution:

Concept:

- Diffusion and drift are the two important processes in the formation of a p-n junction. Diffusion is caused by a carrier concentration gradient; drift is caused by an electric field.
- A junction diode offers low resistance in forward bias and very high resistance in reverse bias, below breakdown. This asymmetric conduction permits rectification.
- A full-wave rectifier uses both half-cycles of an alternating voltage to produce current in the same direction through the load. For ideal diodes, $v_o = V_m |\sin \omega t|$, where V_m is the peak voltage of either half of a centre-tapped secondary.

Step 1: Identify diffusion and drift at the junction When p-type and n-type materials are joined, majority-carrier electrons diffuse from the n-side to the p-side, and holes diffuse from the p-side to the n-side. Recombination near the junction leaves immobile positive donor ions on the n-side and negative acceptor ions on the p-side. This region depleted of mobile charge carriers is the depletion layer. Its electric field points from the n-side to the p-side and produces a drift current opposite to the diffusion current. At equilibrium these currents balance, so the net current is zero. The two processes are therefore **diffusion and drift**.

Step 2: Connect the centre-tapped full-wave rectifier Connect the ends A and B of a centre-tapped transformer secondary to the anodes of diodes D_1 and D_2 , respectively. Join their cathodes at P . Connect the load resistance R_L between P and centre tap O . The alternating supply is applied to the primary; the equal secondary halves supply opposite instantaneous voltages relative to O . The diagram shows conventional load current from P through R_L back to O .



Centre-tapped full-wave rectifier; both cathodes join at P .

Step 3: Trace conduction during the first half-cycle When A is positive relative to O , B is negative

relative to O . Diode D_1 is forward biased and conducts, while D_2 is reverse biased and blocks. Conventional current follows

$$A \longrightarrow D_1 \longrightarrow P \longrightarrow R_L \longrightarrow O \longrightarrow A.$$

The last segment closes the path through the upper half of the secondary. The upper end of the load is positive.

Step 4: Trace conduction during the second half-cycle When the supply polarity reverses, B becomes positive and A negative relative to O . Now D_2 conducts and D_1 blocks. The current path is

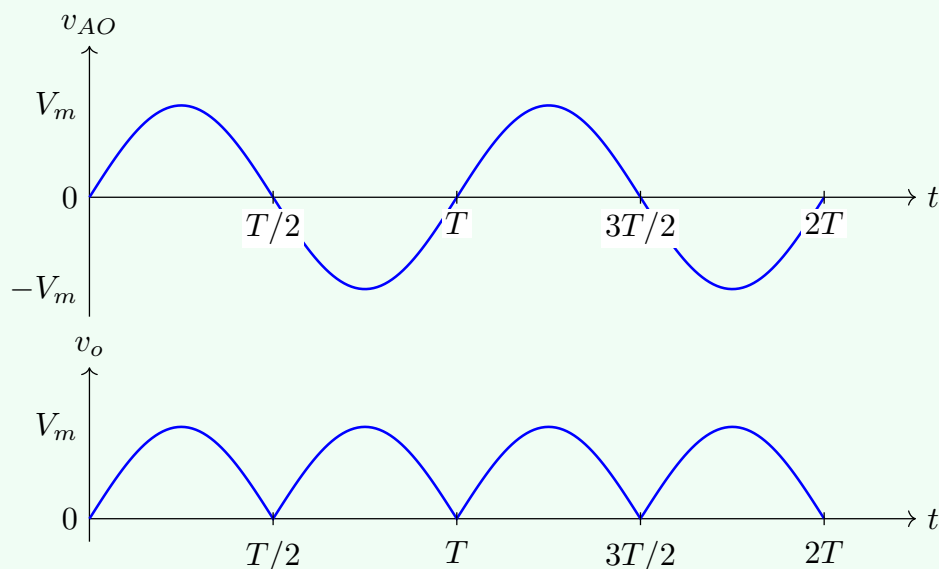
$$B \longrightarrow D_2 \longrightarrow P \longrightarrow R_L \longrightarrow O \longrightarrow B.$$

This path closes through the lower half of the secondary. Current through R_L still flows from P towards O , so both half-cycles give the same output polarity.

Step 5: Draw the waveforms and identify the rectifying property Taking the input reference as $v_{AO} = V_m \sin \omega t$, the other half-secondary voltage is $v_{BO} = -V_m \sin \omega t$. Ignoring the small forward diode drop gives

$$v_o = V_m |\sin \omega t|, \quad i_L = \frac{v_o}{R_L}.$$

The waveform is a succession of positive half-sine pulses. Two output pulses occur in one input period T ; hence the ripple frequency is $2f$, where $f = 1/T$ is the input frequency. This is pulsating direct current; it is not a constant voltage without filtering. The essential diode property is its **unidirectional conduction**, arising from low forward resistance and high reverse resistance.



Input reference voltage and ideal full-wave output on the same time scale.

Step 6: Conclusion The junction-forming processes are **diffusion and drift**. The two diodes conduct alternately, keeping the load current in the same direction during both input half-cycles and producing a full-wave rectified output. A diode's asymmetric forward and reverse conduction makes rectification possible.

Quick Tip to Solve: For each half-cycle, mark which secondary end is positive relative to the centre tap, then trace its conducting diode. Check that both paths cross the load in the same direction.

32(a). (i) Draw a ray diagram to show the working of a compound microscope. Obtain the expression for the total magnification for the final image to be formed at the near point.

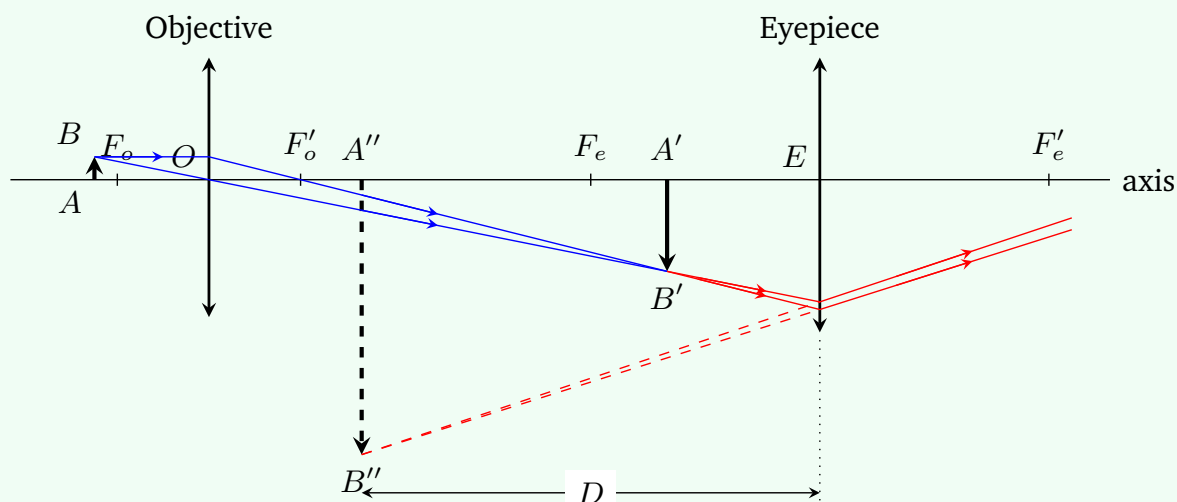
(ii) In a compound microscope an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. If the eye-piece has a focal length of 5 cm and the final image is formed at the near point, find the magnifying power of the microscope. [5 marks]

Solution:

Concept:

- A compound microscope combines a short-focal-length objective with an eyepiece. The objective forms a real enlarged image, which the eyepiece views as a simple microscope.
- For a thin lens, $1/f = 1/v - 1/u$, with Cartesian signed object and image distances u, v . The objective's linear magnification is $m_o = v_o/u_o$.
- Magnifying power is the angular size through the instrument divided by the angular size of the original object viewed unaided at the least distance of distinct vision, $D = 25$ cm. For a near-point image, the eyepiece factor is $M_e = 1 + D/f_e$.

Step 1: (i) Construct the images formed by the two lenses Place the small object AB just beyond the first focal point F_o of the objective O . The objective produces the real, inverted, enlarged image $A'B'$. Arrange the eyepiece E so that $A'B'$ lies between its first focal point F_e and its optical centre. Rays emerging from the eyepiece diverge; their backward extensions meet at B'' . Thus the final image $A''B''$ is virtual, enlarged and inverted relative to AB , at distance D to the left of the eyepiece. Solid rays show actual light and dashed lines show backward extensions; the diagram is schematic.



Compound microscope with final virtual image at the near point; schematic ray paths.

Step 2: (i) Derive the eyepiece factor for a near-point image Let h be the object's height and h' the magnitude of the intermediate image height. Set $v_e = -D$ and $u_e = -s$, where $s > 0$ is the intermediate image's distance from the eyepiece. The lens formula gives

$$\frac{1}{f_e} = -\frac{1}{D} + \frac{1}{s}, \quad \frac{D}{s} = 1 + \frac{D}{f_e}.$$

In the paraxial approximation, the angle through the eyepiece is $\beta \simeq h'/s$, whereas the original object viewed unaided at the near point subtends $\alpha \simeq h/D$. Therefore

$$|M| = \frac{\beta}{\alpha} = \frac{h'}{h} \frac{D}{s} = \frac{v_o}{|u_o|} \left(1 + \frac{D}{f_e} \right).$$

The signed expression is $M = (v_o/u_o)(1 + D/f_e)$; its negative sign indicates inversion. With the usual microscope approximations $|u_o| \simeq f_o$ and $v_o \simeq L$, where L is the effective tube length, the familiar magnitude is $|M| \simeq (L/f_o)(1 + D/f_e)$.

Step 3: (ii) Calculate the objective's image distance and magnification Use the given object distance exactly, rather than the tube-length approximation. Here $u_o = -1.5$ cm and $f_o = +1.25$ cm. Hence

$$\frac{1}{v_o} = \frac{1}{f_o} + \frac{1}{u_o} = \frac{1}{1.25} - \frac{1}{1.5} = \frac{2}{15} \text{ cm}^{-1},$$

$$v_o = 7.5 \text{ cm}, \quad m_o = \frac{7.5}{-1.5} = -5.$$

The positive image distance confirms that the objective's intermediate image is real; the negative linear magnification shows that it is inverted.

Step 4: (ii) Combine the objective and eyepiece factors For $f_e = 5$ cm and the final image at the normal near point,

$$M_e = 1 + \frac{25}{5} = 6, \quad M = m_o M_e = (-5)(6) = -30.$$

The eyepiece enlarges the intermediate image's apparent angular size without reversing its orientation again. Consequently the final image retains the objective's inversion, and the reported magnifying power is the magnitude of this signed value.

Step 5: Conclusion For a final image at the near point, $|M| = \frac{v_o}{|u_o|}(1 + D/f_e) \simeq \frac{L}{f_o}(1 + D/f_e)$. The given microscope has magnifying power 30, with signed magnification $M = -30$; its final image is virtual and inverted.

Quick Tip to Solve: For a near-point image include the eyepiece's +1: use $1 + D/f_e$. When u_o is given, calculate v_o first and use $v_o/|u_o|$, avoiding an unnecessary tube-length approximation.

OR

32(b). (i) Draw a ray diagram for the formation of image of an object by an astronomical telescope, in normal adjustment. Obtain the expression for its magnifying power.

(ii) The magnifying power of an astronomical telescope in normal adjustment is 2.9 and the objective and the eyepiece are separated by a distance of 150 cm. Find the focal lengths of the two lenses.

[5 marks]

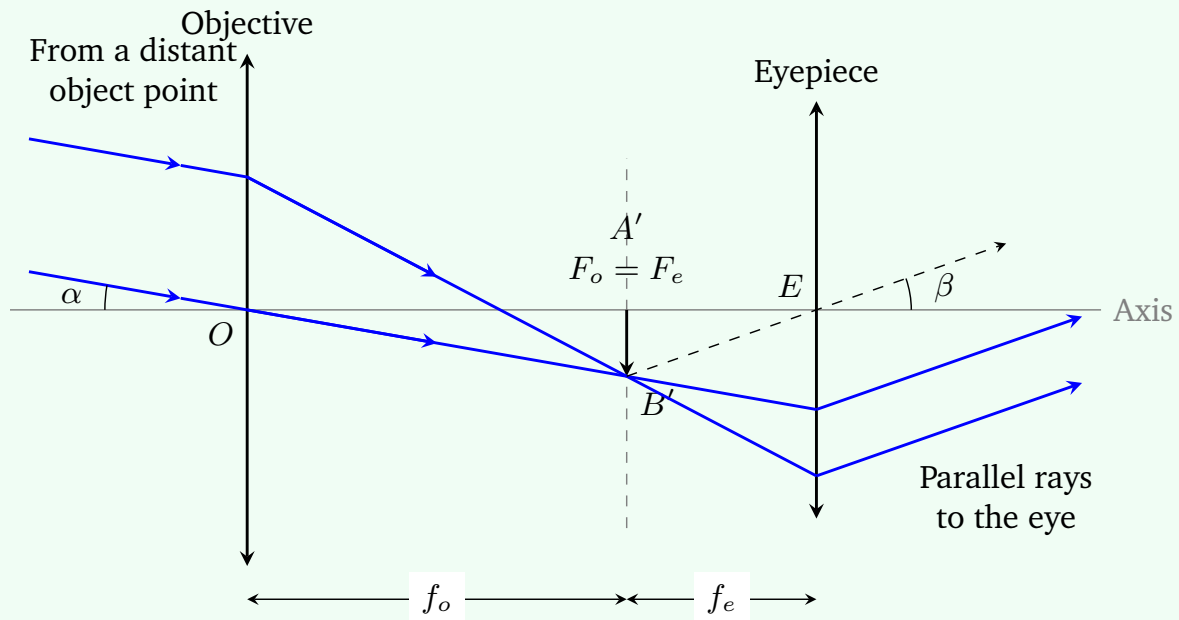
Solution:

Concept:

- An astronomical telescope uses a convex objective of focal length f_o and a convex eyepiece of focal length f_e . The objective forms a real, inverted image of a distant object in its focal plane.
- In normal adjustment the intermediate image lies in the first focal plane of the eyepiece, so the emerging rays are parallel and the final image is at infinity. The lens separation is $L = f_o + f_e$.
- Angular magnifying power is $M = \beta/\alpha$, where α is the angle subtended by the distant object at the unaided eye and β is the angle subtended by the final image. For paraxial rays, small angles in radians may be replaced by their tangents.

Step 1: (i) Form the intermediate and final images Light from a distant point reaches the objective as a parallel bundle inclined slightly to the principal axis. The objective brings this bundle to the point B'

in its focal plane. The foot A' of the intermediate image lies on the axis. Position the eyepiece so that its first focus F_e coincides with the objective's second focus F_o . Thus the real, inverted intermediate image $A'B'$ is a focal-plane object for the eyepiece. The eyepiece converts the diverging rays from B' into a parallel emergent bundle; the final image is virtual, inverted relative to the distant object, and at infinity. The eye views this bundle without accommodation.



Astronomical telescope in normal adjustment: the common focal plane contains the inverted intermediate image; the incident and emergent bundles are each parallel. The dashed chief ray through the eyepiece centre indicates the viewing angle.

Step 2: (i) Derive the angular magnifying power Let the magnitude of the intermediate image height be $h = A'B'$. With small angles, the objective and eyepiece triangles give

$$|\alpha| \simeq \frac{h}{f_o}, \quad |\beta| \simeq \frac{h}{f_e}.$$

Dividing cancels the intermediate image height:

$$|M| = \frac{|\beta|}{|\alpha|} = \frac{h/f_e}{h/f_o} = \frac{f_o}{f_e}.$$

The final image is inverted, so the signed magnifying power is

$$M = -\frac{f_o}{f_e}.$$

When a positive magnifying power is quoted for an astronomical telescope, it denotes its magnitude. The negative sign expresses inversion and does not make either convex lens's focal length negative.

Step 3: (ii) Find the focal lengths Here $|M| = 2.9$ and $L = 150$ cm. Normal adjustment supplies two independent equations:

$$\frac{f_o}{f_e} = 2.9, \quad f_o + f_e = 150 \text{ cm}.$$

Substitute $f_o = 2.9f_e$ in the separation equation:

$$2.9f_e + f_e = 150 \text{ cm},$$

$$3.9f_e = 150 \text{ cm},$$

$$f_e = \frac{150}{3.9} \text{ cm} \simeq 38.46 \text{ cm}.$$

Then the objective focal length is

$$f_o = 150 - 38.46 = 111.54 \text{ cm} \quad (\text{approximately}).$$

As a check, these values add to 150 cm and their ratio is approximately 2.9. The objective has the larger focal length, as required for angular magnification.

Step 4: Conclusion In normal adjustment, $M = -f_o/f_e$ and $L = f_o + f_e$; the image is inverted and at infinity. The focal lengths are $f_o \simeq 111.54 \text{ cm}$ for the objective and $f_e \simeq 38.46 \text{ cm}$ for the eyepiece.

Quick Tip to Solve: For a normal-adjustment telescope, combine the sum and ratio directly: $f_e = L/(|M| + 1)$, then $f_o = L - f_e$. Use the magnitude of the quoted magnifying power.

33(a)(i). Explain how free electrons in a metal at constant temperature attain an average velocity under the action of an electric field. Hence obtain an expression for it. [3 marks]

Solution:

Concept:

- Drift velocity is the average velocity acquired by free electrons in a conductor under an applied electric field. Random thermal velocities have zero vector average in the absence of the field.
- For an electron of charge $-e$ and mass m , the electric force is $\vec{F} = -e\vec{E}$, so its acceleration between collisions is $\vec{a} = -e\vec{E}/m$. Here e is the positive magnitude of electronic charge.
- In the relaxation-time description, τ is the average time since the last scattering event. Averaging the field-induced change in velocity over the free electrons gives the drift velocity.

Step 1: Describe electron motion without the field Free electrons move continuously and randomly through the metal and undergo frequent collisions with the lattice. At constant temperature their random motion remains statistically steady. Although individual electrons have nonzero velocities, all directions are equally likely, so the vector sum of these velocities averages to zero. Thus thermal motion alone produces no net current.

Step 2: Apply the field and average over collisions On applying an electric field $\vec{E}$, each electron accelerates opposite to the field because its charge is negative. Collisions randomise its motion repeatedly, so electrons do not acquire an indefinitely increasing average velocity. A small directed velocity is superposed on the random motion. Let $\vec{u}_i$ be the random velocity of the i th electron just after its last collision and t_i the time elapsed since that collision. Between collisions,

$$\vec{v}_i = \vec{u}_i - \frac{e\vec{E}}{m}t_i.$$

In the relaxation-time model, averaging over the electrons gives $\langle \vec{u}_i \rangle = 0$ and $\langle t_i \rangle = \tau$. Hence,

$$\begin{aligned}\vec{v}_d &= \langle \vec{v}_i \rangle = \langle \vec{u}_i \rangle - \frac{e\vec{E}}{m} \langle t_i \rangle \\ &= -\frac{e\tau}{m} \vec{E}.\end{aligned}$$

Its magnitude is $v_d = eE\tau/m$. The negative sign in the vector expression specifies electron drift opposite to the field; conventional current is along the field. Repeated scattering permits this steady average velocity at constant temperature.

Step 3: Conclusion The steady average velocity is $\vec{v}_d = -e\tau\vec{E}/m$, opposite to the field; its magnitude is $v_d = eE\tau/m$. Here e is the positive electronic charge magnitude, m is the electron mass, and τ is the relaxation time.

Quick Tip to Solve: Average vector velocities, not speeds: the random thermal contribution cancels, while the field-induced contribution survives as $-e\tau\vec{E}/m$.

33(a)(ii). Consider two conducting wires A and B of the same diameter but made of different materials joined in series across a battery. The number density of electrons in A is 1.5 times that in B. Find the ratio of drift velocity of electrons in wire A to that in wire B. [2 marks]

Solution:

Concept:

- The current carried by electrons of drift speed v_d is $I = neAv_d$, with number density n , electronic charge magnitude e , and cross-sectional area A .
- In a steady series circuit the same current flows through both wires, since charge cannot continually accumulate at their junction. Equal diameters give equal cross-sectional areas.

Step 1: Write the equal-current condition Let the common area be A , and denote the drift speeds by v_A and v_B . Applying the current formula to the two materials gives

$$I = n_A e A v_A = n_B e A v_B.$$

Cancelling the common factors eA , we find $n_A v_A = n_B v_B$. The carrier densities differ, so the common current does not require equal drift speeds.

Step 2: Substitute the given density ratio The question gives $n_A = 1.5n_B$. Therefore

$$\frac{v_A}{v_B} = \frac{n_B}{n_A} = \frac{1}{1.5} = \frac{2}{3}.$$

Wire A has more mobile electrons per unit volume, so each electron needs a smaller average drift speed to transport the same charge per second. The electric fields in the different materials need not be equal.

Step 3: Conclusion The ratio of electron drift speeds is $v_A : v_B = 2 : 3$.

Quick Tip to Solve: For wires in series, cancel the common current first; with equal diameters, invert the given carrier-density ratio to obtain the drift-speed ratio.

33(b)(i). A cell emf (E) and internal resistance (r) is connected across a variable load resistance (R). Draw plots showing the variation of terminal voltage V with (i) R and (ii) the current (I) in the load. [2 marks]

Solution:

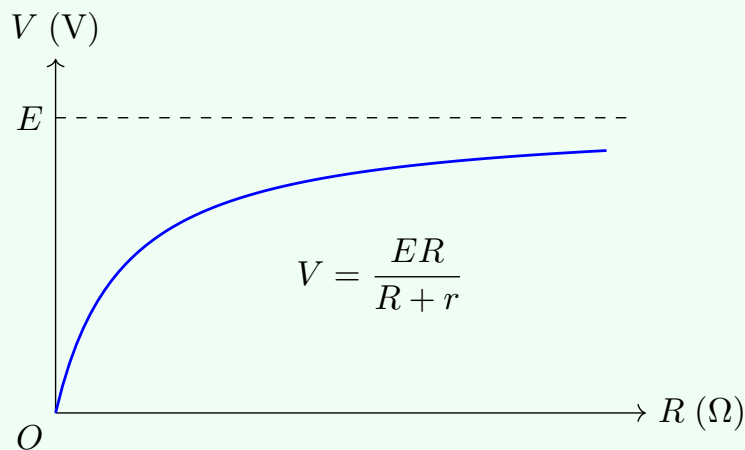
Concept:

- A cell of emf E and internal resistance r , supplying current I , has terminal voltage $V = E - Ir = IR$, where R is its load resistance.
- For positive internal resistance, increasing the load resistance reduces the internal voltage drop. At open circuit $V = E$; at short circuit $V = 0$.

Step 1: Express terminal voltage in terms of load resistance Applying the loop rule to the cell and its load gives $E = I(R + r)$. Hence

$$I = \frac{E}{R + r}, \quad V = IR = \frac{ER}{R + r}.$$

At $R = 0$, the terminals are short-circuited and $V = 0$. As R increases, the current and internal voltage drop decrease, so V increases. The slope $dV/dR = Er/(R + r)^2$ is positive but decreases: the curve rises with decreasing steepness. For an open circuit, $R \rightarrow \infty$, $I \rightarrow 0$ and $V \rightarrow E$. Thus $V = E$ is a horizontal asymptote, not a finite-resistance intercept.

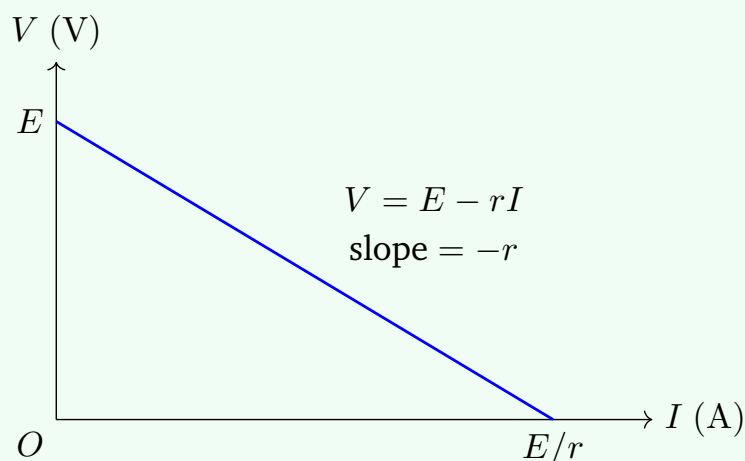


Terminal voltage rises towards the open-circuit emf as load resistance increases.

Step 2: Express terminal voltage in terms of load current The internal resistance causes a voltage loss Ir , giving

$$V = E - rI.$$

This is a straight line with vertical intercept E and slope $-r$. It meets the current axis at the short-circuit current $I = E/r$. The graph for a passive variable load is the segment between $(0, E)$ and $(E/r, 0)$, since $0 \leq I \leq E/r$.



Terminal voltage decreases linearly with load current; the slope is negative internal resistance.

Step 3: Conclusion The V -versus- R plot rises from the origin towards the horizontal asymptote $V = E$. The V -versus- I plot is a straight line of slope $-r$, joining $(0, E)$ to $(E/r, 0)$.

Quick Tip to Solve: Mark the open-circuit and short-circuit limits before drawing either plot; $V = E$ is reached only as the load resistance tends to infinity.

33(b)(ii). Three cells, each of emf E but internal resistances $2r$, $3r$ and $6r$ are connected in parallel across a resistor R . Obtain expressions for (i) current flowing in the circuit, and (ii) the terminal potential difference across the equivalent cell. [3 marks]

Solution:

Concept:

- Cells in parallel have a common terminal potential difference V . Identical emfs with like terminals joined give equivalent emf E , independent of their internal resistances.
- For a branch with emf E and internal resistance r_k , the outward current is $I_k = (E - V)/r_k$. Kirchhoff's junction rule gives the total load current $I = \sum I_k$, and Ohm's law gives $V = IR$.

Step 1: Replace the three parallel cells by one equivalent cell Join the positive terminals together and the negative terminals together. Since each cell has emf E , their common open-circuit voltage remains E ; parallel connection does not add the emfs. The equivalent internal resistance is

$$\frac{1}{r_{\text{eq}}} = \frac{1}{2r} + \frac{1}{3r} + \frac{1}{6r} = \frac{3 + 2 + 1}{6r} = \frac{1}{r}, \quad r_{\text{eq}} = r.$$

Alternatively, the individual currents are $(E - V)/(2r)$, $(E - V)/(3r)$ and $(E - V)/(6r)$. Adding them gives $I = (E - V)/r$, which verifies the equivalent-cell relation.

Step 2: Calculate load current and terminal potential difference The equivalent cell of emf E and internal resistance r supplies the external resistor R . The total series resistance seen by its emf is $R + r$. Therefore

$$I = \frac{E}{R + r}, \quad V = IR = \frac{ER}{R + r}.$$

This I is the total current in the external circuit, not the current of any single branch. The branch currents divide in the ratio $1/(2r) : 1/(3r) : 1/(6r) = 3 : 2 : 1$, consistent with their sum equalling I .

Step 3: Conclusion The equivalent cell has $E_{\text{eq}} = E$ and $r_{\text{eq}} = r$. Its external current is $I = E/(R + r)$, and its terminal potential difference is $V = ER/(R + r)$.

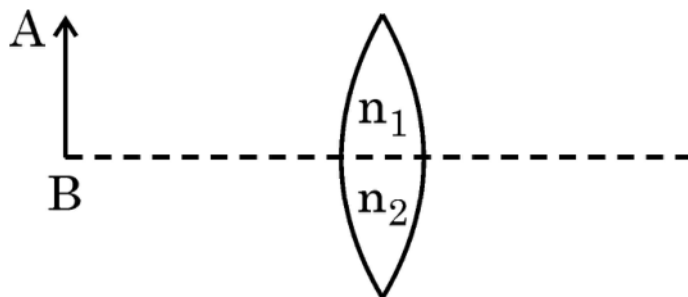
Quick Tip to Solve: Equal emfs in parallel retain the same emf. Add the reciprocals of their internal resistances before applying the series load formula.

Section E (8 marks)

Note : Questions number 34 and 35 are Case Study based questions. Read the following paragraph and answer the questions.

34. A lens is a transparent optical medium bounded by two surfaces; at least one of which should be spherical. Considering image formation by a single spherical surface successively at the two surfaces of a lens, lens maker's formula is obtained. It is useful to design lenses of desired focal length using surfaces of suitable radii of curvature. This formula helps us obtain a relation between u , v and f for a lens. Lenses form images of objects and they are used in a number of optical devices, for example microscopes and telescopes. [4 marks]

34(i). An object AB is kept in front of a composite convex lens, as shown in figure. Will the lens produce one image? If not, explain. [1 mark]



Solution:

Concept:

- Lens maker's formula in air is $1/f = (n - 1)(1/R_1 - 1/R_2)$: focal length depends on refractive index n as well as surface curvatures.
- Each portion of a lens can form a complete image; for object distance u , the image distance obeys $1/v - 1/u = 1/f$.

Step 1: Compare the two lens portions The upper and lower portions have refractive indices n_1 and n_2 , respectively. With the same surface curvatures but different refractive indices, their powers differ. Thus their focal lengths f_1 and f_2 are different.

Step 2: Locate the images independently Both portions receive light from the entire object AB. For the same u , the relations $1/v_1 = 1/f_1 + 1/u$ and $1/v_2 = 1/f_2 + 1/u$ give different image distances. The portions do not separately reproduce just the top and bottom of the object.

Step 3: Conclusion No. For the different refractive indices shown, two complete images are formed at different positions because the two portions have different focal lengths.

Quick Tip to Solve: A partial lens still images the complete object. Here count the distinct focal lengths caused by the two refractive indices.

34(ii). A real image of an object formed by a convex lens is observed on a screen. If the screen is removed, will the image still be formed? Explain. [1 mark]

Solution:

Concept:

- A real image is formed where refracted rays from each object point actually converge.
- A screen scatters the light reaching the image plane so that the image can be viewed from different directions; it does not cause the convergence.

Step 1: Identify what fixes the image position The convex lens refracts rays from the object and brings them to corresponding image points. The lens focal length and object distance determine this position through $1/v - 1/u = 1/f$. The presence of a screen does not enter this relation.

Step 2: Follow the rays after removing the screen Removing the screen leaves the object, lens and refracted paths unchanged. The rays still meet at the same image points and then diverge beyond them. An eye placed suitably beyond the image plane can receive these rays and observe the image, although the screen's diffuse display is absent.

Step 3: Conclusion Yes. The real image is still formed at the same position because the lens continues to converge the rays there; the screen only makes that image conveniently visible.

Quick Tip to Solve: Distinguish ray convergence from viewing: removing a screen changes how an image is observed, not where the lens brings rays to a focus.

34(iii). A double convex lens is made of glass of refractive index 1.55 with both faces of the same radius of curvature. Find the radius of curvature required if focal length is 20 cm. [2 marks]

Solution:

Concept:

- For a thin lens in air, lens maker's formula is $1/f = (n - 1)(1/R_1 - 1/R_2)$, where n is the glass refractive index and R_1, R_2 are signed surface radii.
- Using the Cartesian convention for light travelling left to right, a symmetric double convex lens has $R_1 = +R$ and $R_2 = -R$, with R their common positive magnitude.

Step 1: Assign the radii and focal-length signs The lens converges light in air, so its given focal length is $f = +20$ cm. The first surface has its centre of curvature to the right and the second to the left. Although their radius magnitudes are equal, their signs are opposite. Substitute $R_1 = R$, $R_2 = -R$ and $n = 1.55$:

$$\frac{1}{f} = (1.55 - 1) \left(\frac{1}{R} - \frac{1}{-R} \right) = \frac{2(0.55)}{R}.$$

Step 2: Solve for the common radius magnitude Rearranging the equation before inserting the focal

length keeps the signs explicit:

$$R = 2(n - 1)f = 2(0.55)(20 \text{ cm}) = 22 \text{ cm}.$$

The value is a radius of curvature, not the lens diameter. As a check, the surface terms add rather than cancel, so the computed power is positive, as required for a double convex glass lens in air.

Step 3: Conclusion Each face must have radius of curvature of magnitude 22 cm ; the signed radii are $R_1 = +22 \text{ cm}$ and $R_2 = -22 \text{ cm}$.

Quick Tip to Solve: For a symmetric double convex lens in air use $R = 2(n - 1)f$, remembering that equal radius magnitudes mean opposite signed radii.

OR

34(iii). Two convex lenses A and B of focal lengths 15 cm and 10 cm respectively are placed coaxially 'd' distance apart. A point object is kept at a distance of 30 cm in front of lens A. Find the value of 'd' so that the rays emerging from lens B are parallel to its principal axis. [2 marks]

Solution:

Concept:

- For a thin lens, $1/v - 1/u = 1/f$, where distances are measured from the lens using the Cartesian sign convention.
- A convex lens sends rays parallel to its principal axis when its object lies at its first principal focus. The image formed by lens A serves as the object for lens B.

Step 1: Locate the image formed by lens A Take the direction of incident light as positive. For lens A, $u_A = -30 \text{ cm}$ and $f_A = +15 \text{ cm}$. Thus

$$\frac{1}{v_A} = \frac{1}{f_A} + \frac{1}{u_A} = \frac{1}{15} - \frac{1}{30} = \frac{1}{30} \text{ cm}^{-1}.$$

The image is therefore formed 30 cm to the right of A. This also follows from the familiar result that an object at $2f_A$ forms a real image at $2f_A$.

Step 2: Place the image at the first focus of B Parallel emergence means $v_B \rightarrow \infty$. Applying the lens formula to B gives $u_B = -f_B = -10 \text{ cm}$. The image of A must therefore lie 10 cm to the left of B. With A at coordinate zero and B at coordinate d ,

$$u_B = 30 - d = -10 \text{ cm}.$$

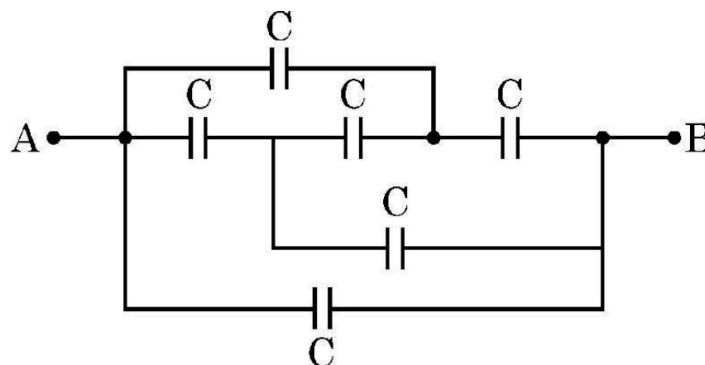
Hence the separation is the image distance from A plus the focal length of B, not their difference.

Step 3: Conclusion The required distance between the lenses is $d = 40 \text{ cm}$.

Quick Tip to Solve: First locate A's image, then place B one focal length beyond that image so that the emerging beam is parallel.

35. A capacitor is a system of two conductors separated by an insulator. The two conductors have equal and opposite charges with a potential difference between them. The capacitance of a capacitor depends on the geometrical configuration (shape, size and separation) of the system and also on the nature of the insulator separating the two conductors. They are used to store charges. Like resistors, capacitors can be arranged in series or parallel or a combination of both to obtain desired value of capacitance. [4 marks]

35(i). Find the equivalent capacitance between points A and B in the given diagram. [1 mark]



Solution:

Concept:

- Equal capacitors in a symmetric bridge put its two intermediate nodes at the same potential; the capacitor between those nodes has zero voltage.
- Series capacitances obey $1/C_s = 1/C_1 + 1/C_2$; parallel capacitances add directly.

Step 1: Identify the balanced bridge Call the junction between the first two horizontal capacitors X and the junction between the second and third Y. Between A and B, the paths A–X–B and A–Y–B each contain two identical capacitors C . Therefore X and Y have equal potential. The central capacitor connecting X to Y has no charge and does not affect the equivalent capacitance.

Step 2: Combine the remaining branches Each two-capacitor series path has capacitance $C/2$. These two paths and the bottom capacitor C , directly between A and B, are in parallel:

$$C_{eq} = \frac{C}{2} + \frac{C}{2} + C.$$

Step 3: Conclusion The equivalent capacitance is $C_{eq} = 2C$.

Quick Tip to Solve: Check the two internal nodes for equal potential before combining capacitors in an apparent bridge network.

35(ii). A dielectric slab is inserted between the plates of a parallel plate capacitor. The electric field between the plates decreases. Explain. [1 mark]

Solution:

Concept:

- A dielectric becomes polarised in an applied electric field: its bound positive and negative charges are displaced slightly in opposite directions.
- The polarisation field opposes the field of the free charges on the plates, reducing their resultant

field when the plate charge is fixed.

Step 1: Explain the induced surface charges Inserting the dielectric polarises its molecules. Its surface next to the positive plate acquires negative bound charge, while the opposite surface acquires positive bound charge. These are bound charges; the dielectric does not conduct charge across the gap.

Step 2: Superpose the two fields The field E_p produced by these bound surface charges is opposite to the original plate field E_0 . Thus the field in the dielectric is $E = E_0 - E_p$. For a completely filled capacitor with fixed free charge and dielectric constant K , $E = E_0/K$. This is the isolated-capacitor condition implicit in the stated decrease; at fixed battery voltage, a fully filled capacitor instead retains $E = V/d$.

Step 3: Conclusion Dielectric polarisation produces an opposing electric field, so the resultant field is reduced for unchanged free charge on the plates.

Quick Tip to Solve: Show the induced negative dielectric surface beside the positive plate; its field then clearly opposes the plate field.

35(iii). A capacitor A of capacitance C , having charge Q is connected across another uncharged capacitor B of capacitance $2C$. Find an expression for (a) the potential difference across the combination and (b) the charge lost by capacitor A. [2 marks]

Solution:

Concept:

- Capacitors connected across the same two terminals are in parallel and attain a common final potential difference V_f .
- In the isolated combination, charge is conserved. For a capacitor of capacitance C_i , the magnitude of charge on either plate is $Q_i = C_i V_f$.

Step 1: Find the common potential difference Initially A has capacitance C and charge magnitude Q , while B has capacitance $2C$ and is uncharged. On connection, charge flows from A to B until their potential differences become equal. The total charge on the joined positive-side plates remains Q ; their negative-side partners carry $-Q$. The parallel capacitance is $C + 2C = 3C$, hence

$$Q = (C + 2C)V_f, \quad V_f = \frac{Q}{3C}.$$

Step 2: Find the charge lost by A The final charge magnitude on A is its capacitance times the common potential difference:

$$Q_{A,f} = CV_f = C \frac{Q}{3C} = \frac{Q}{3}.$$

The charge lost by either initially charged plate, in magnitude, is its initial charge minus its final charge:

$$\Delta Q_A = Q - Q_{A,f} = Q - \frac{Q}{3}.$$

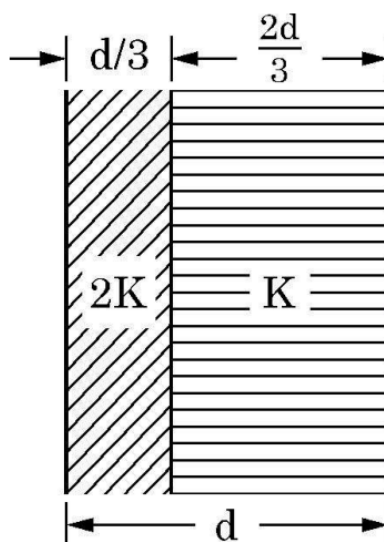
As a check, B gains $2CV_f = 2Q/3$, exactly the charge transferred from A on the corresponding connected plates.

Step 3: Conclusion (a) The potential difference across the combination is $V_f = Q/(3C)$. (b) The charge lost by capacitor A is $2Q/3$.

Quick Tip to Solve: Conserve charge to find the common voltage first; then multiply that voltage by each capacitor's own capacitance.

OR

35(iii). Two slabs of dielectric constants $2K$ and K fill the space between the plates of a parallel plate capacitor of plate area A and plate separation d as shown in figure. Find an expression for capacitance of the system. [2 marks]



Solution:

Concept:

- A parallel plate capacitor filled with dielectric constant K_r , plate area A , and thickness t has capacitance $C = K_r \epsilon_0 A/t$, neglecting edge effects.
- Dielectric layers stacked along the plate separation act as capacitors in series. Their charge magnitudes are equal and their potential differences add.

Step 1: Read the layer thicknesses from the figure The printed separation d is divided into a layer of dielectric constant $2K$ with thickness $d/3$ and a layer of dielectric constant K with thickness $2d/3$. Each layer occupies the full plate area A . Therefore their individual equivalent capacitances are

$$C_1 = \frac{2K\epsilon_0 A}{d/3} = \frac{6K\epsilon_0 A}{d},$$

$$C_2 = \frac{K\epsilon_0 A}{2d/3} = \frac{3K\epsilon_0 A}{2d}.$$

Step 2: Add the potential drops through the layers The field crosses the two dielectric layers

successively between the plates, so they form a series combination. Hence

$$\begin{aligned}\frac{1}{C_{\text{eq}}} &= \frac{1}{C_1} + \frac{1}{C_2} \\ &= \frac{d}{6K\varepsilon_0 A} + \frac{2d}{3K\varepsilon_0 A} = \frac{5d}{6K\varepsilon_0 A}.\end{aligned}$$

No division of the plate area is needed: the fractions in the diagram specify thicknesses, not area fractions.

Step 3: Conclusion The capacitance of the system is $C_{\text{eq}} = \frac{6K\varepsilon_0 A}{5d}$.

Quick Tip to Solve: Follow the labelled separation d : layers encountered successively across this distance combine in series.